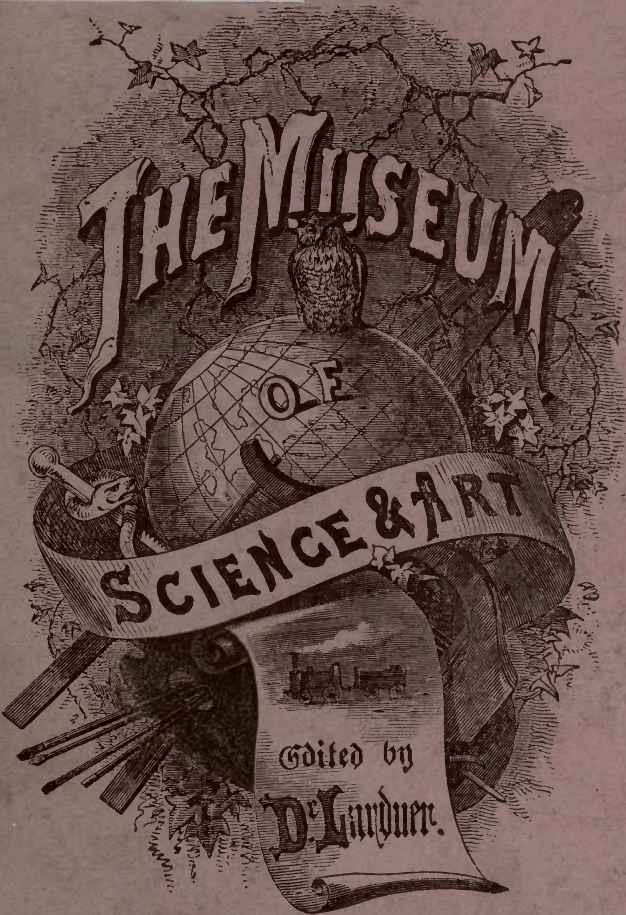

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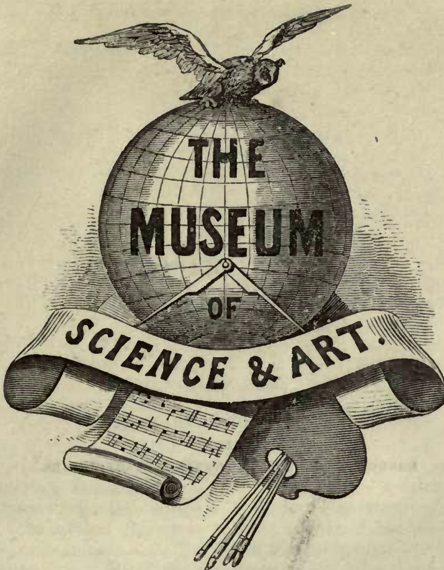

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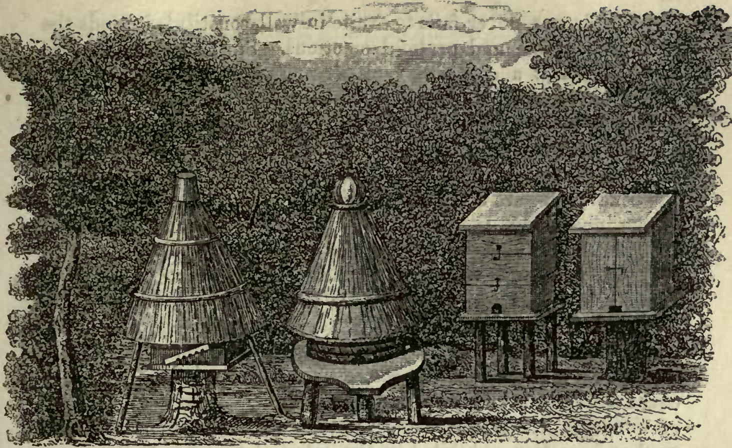


Fig. 54.—Uncovered Apiary.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER I.

1. Moral suggested by economy of nature.—2. Antiquity of apiarian researches—Hebrew scriptures—Aristomachus—Philiscus—Aristotle—Virgil.—3. Modern observers.—4. Huber.—5. His servant Burnens—curious history of his blindness.—6. His wife and son.—7. Pursuit of his researches.—8. Structure of insects.—9. Plan of their anatomy.—10. Hymenoptera.—11. Varieties of bees.—12. Hive bee.—13. The queen—her numerous suitors.—14. Her chastity and fidelity.—15. Her fertility.—16. Her first laying.—17. Royal eggs.—18. Royal chamber.—19. Effect of her postponement of her nuptials.—20. The drones.—21. The workers.—22. Structure and members of the bee.—23. Mouth and appendages.—24. Use of proboscis.—25. Structure of tongue.—26. Honey-bag.—27. Stomach.—28. Antennæ.—29. Wings.—30. Legs.—31. Feet.—32. Sting.—33. Organs of fecundation and reproduction.—34. Number of eggs produced by the queen.

1. Nature offers herself to human contemplation under no aspects so fascinating, as those in which she renders manifest the provident care of the Creator for the well-being of his creatures. The spectacle of infinite wisdom directing infinite power to bound-

less beneficence, never fails to excite in well-constituted minds the most pleasurable and grateful emotions. Such views of Nature are the truest and purest fountains of that reverential love, which so eminently distinguishes the Christian from all other forms of worship.

In the notices from time to time given in this series of the stupendous works of creation presented in the heavens, and of the benevolent care displayed in the supply of the physical wants of the inhabitants, not of the terrestrial globe * alone, but also of the planets,† which, in company with the earth, revolve round the sun, numerous examples of such beneficence are presented. The vast dimensions of these works, as well as the great importance and the countless numbers of the objects to be provided for, leading the mind naturally to expect a system of provisions established on a corresponding scale, their display, while it excites equal admiration and reverence, produces a less intense sentiment of wonder. When, however, we turn our view from the vast works of creation exhibited in the celestial regions, to the more minute ones presented in the organised world around us, our wonder is as much excited as our admiration, at beholding the same traces of Divine care in the economy of an insect, as were observed in the structure and motions of a planet. There are the same infinite wisdom and foresight, the same unapproachable skill, the same boundless goodness directed to the maintenance of the species and the well-being of the individual, as we have seen displayed in the provisions for a globe a thousand times larger than the earth, or for a cluster of worlds millions of times more numerous than the entire solar system, sun, earth, planets, moons, and all! We have thus before us a demonstration that as the most stupendous works of the universe—the expression of whose dimensions surpasses the powers of arithmetic—are not above Divine control and superintendence, so neither are the most insignificant of creatures—whose existence and structure can be made evident only by the microscope—below the same benevolent care.

2. Among the numerous examples, suggestive of reflections such as these, presented by the insect-world, there is none more remarkable than the little creature, to the character and economy of which we shall devote this notice. How true this is, is proved by the examples of those who, in all ages of the world, have devoted their labours to the observation and investigation of its character and habits. In the Hebrew Scriptures numerous allusions to the bee show that, in those remote times, it had already

* See Tracts on the Earth, Geography, Terrestrial Heat, Air, Water, &c.

† See the Planets, are they inhabited ? the Sun, the Moon, the Stellar Universe, &c.

been a subject of attention with the wisest and the best. Pliny relates that Aristomachus of Soli in Cilicia devoted fifty-eight years of his life to the study of the bee; and that Philiscus, the Thracian, passed so large a part of his time in the woods observing its habits, that he acquired the title of AGRIUS. Among his numerous researches in natural history, Aristotle assigned a considerable share to the bee; and Virgil devoted to it the fourth book of his Georgics:—

> "Protenus aërii mellis cœlestia dona
> Exsequar. Hanc etiam, Mæcenas, adspice partem.
> Admiranda tibi levium spectacula rerum,
> Magnanimosque duces, totiusque ordine gentis
> Mores, et studia, et populos, et prælia dicam.
> In tenui labor; at tenuis non gloria, si quem
> Numina læva sinunt, auditque vocatus Apollo."
>
> GEORG. IV. 1—7.

> "The gifts of Heaven my following song pursues,
> Aërial honey, and ambrosial dews.
> Mæcenas, read this other part that sings
> Embattled squadrons and advent'rous kings—
> Their arms, their arts, their manners, I disclose,
> And how they war and whence the people rose.
> Slight is the subject, but the praise not small
> If Heaven assist, and Phœbus hear my call."
>
> DRYDEN.

3. In modern times the bee has been the subject of the observations and researches of some of the most eminent naturalists, among whom may be mentioned Swammerdam (1670), Maraldi (1712), Ray, Reaumur (1740), Linnæus, Bennet, Schirach, John Hunter, Huber—father and son,—and more recently Kirby, whose monograph upon the English bees may be regarded as a classic in natural history.

4. Among these, the elder Huber stands pre-eminent, not only for the extent and importance of his contributions to the history of the insect, but for the remarkable circumstances and difficulties under which his researches were prosecuted. Visited with the privation of sight at the early age of seventeen, his observations were made with the eyes and his experiments performed with the hands of others; and, notwithstanding this discouragement and obstacles which might well have been regarded as insurmountable, he continued his labours for forty years, during which he made those discoveries which have conferred upon him such celebrity.

5. Happily for science, Huber, after losing his sight and at the commencement of his researches, had in his service a domestic, named François Burnens, a native of the Pays de Vaud, in Switzerland. Reading and writing constituted the extent of the

education of this person; but nature had bestowed upon him faculties which, with better opportunities, would have rendered him an eminent naturalist. Huber commenced by employing him as a reader.

He read to his master various works on physics, and, among others, those of Reaumur, in which the admirable observations of that naturalist on the bee are so clearly and beautifully stated. Huber soon perceived by the observations and reflections of his reader, and by the consequences he deduced from what he read, that he had at his disposition no ordinary person, and resolved to profit by him. He accordingly procured the means of prosecuting a series of observations on the economy of the bee, with the aid of the eyes, the hands, and the intelligence of Burnens. All the observations of Reaumur were first repeated, and the accordance of the phenomena, as described by Burnens, with those which had been recorded by Reaumur, gave Huber full confidence; and the master and servant, quitting the beaten path, entered upon new ground, and during a period of fifteen years, prosecuted those researches in the natural history and economy of the bee, which, being committed to writing by the hand of Burnens at the dictation of Huber, were published in one volume about 1792, in form of letters addressed by Huber to Bonnet.

6. Soon after this, Huber lost his invaluable colleague, for servant he had long ceased to be. Burnens was recalled by family ties to his native place, where the personal estimation in which he was held caused him to be raised to a high position in the local magistracy.

Previously to this, Huber had the good fortune to consolidate his domestic happiness by marriage. "My separation from my faithful and zealous Burnens," said Huber, "which was not the least cruel of the misfortunes with which I was visited, was, however, softened by the satisfaction which I felt in observing Nature through the eyes of the being who was dearest to me, and with whom I could commune with pleasure on the most elevated topics. But what more than all the rest contributed to attach me to natural history, was the taste manifested by my son for that subject. I explained to him the results of my observations and researches. He expressed the regret he felt that labours which would, as it seemed to him, so deeply interest naturalists should remain buried in my portfolio. Perceiving, meanwhile, the secret repugnance that I felt against the task of reducing them to order, he proposed to take charge of that labour."

7. From that time our great naturalist was again consoled, by having at his disposal two pair of eyes in place of one. The wife and the son, animated by a common enthusiasm, and urged by

conjugal and filial devotion, more than compensated for the loss of Burnens; and the observations and researches were pursued with unabated zeal, and were finally collected and published in the second volume, which appeared about 1814, more than twenty years after the publication of the first.*

8. Since any explanation, however popular and familiar, of the economy and habits of the bee, must necessarily involve very frequent references to its structure and organs, it will be convenient in the first instance briefly to explain the terms, by which naturalists have designated its several parts.

The body of insects in general consists of a series of annular segments, so articulated one to another as to allow more or less flexibility. It consists of three chief parts, the *head*, the *thorax*, and the *abdomen*.

The head consists of a simple segment, the thorax of three, and the abdomen of a greater number, sometimes as many as nine. Each segment is distinguished by its ventral or inferior, and dorsal or superior part.

Insects have three pairs of legs, which are inserted in the sides of the ventral parts of the three thoracic segments of the body; and generally two pairs of wings, which are inserted in the sides of the dorsal parts of the second and third thoracic segments, counting from the anterior to the posterior part of the body.

A pair of members, called *antennæ*, are inserted in the sides of the head, varying much in structure in different classes, and in many, including the bee, have the form of slender and flexible horns, consisting of many minute pieces articulated one to another. These are generally presumed to be tactile organs, and are consequently sometimes called *feelers*.

9. This description will be more easily comprehended by reference to the annexed diagram, fig. 1, which may be taken as a general theoretical representation of the structure of an insect.

As here indicated, the three thoracic segments are distinguished as the pro-, meso-, and metathorax.

10. Insects have been classified by naturalists according to the structure of their wings, and the order to which the bee has been assigned, and of which it is regarded as the type, is the *Hymenoptera*, a compound of two Greek words signifying membranaceous wings.

The section or subsection of the order of Hymenoptera, which in its economy and peculiar construction differs most from all other orders of insects, has been designated by Latreille *Mellifera*,

* "Nouvelles Observations sur les Abeilles." Paris, 1814.

a Latin word signifying Honey-Gatherers; or *Anthophila*, a Greek word signifying Flower-Lovers.

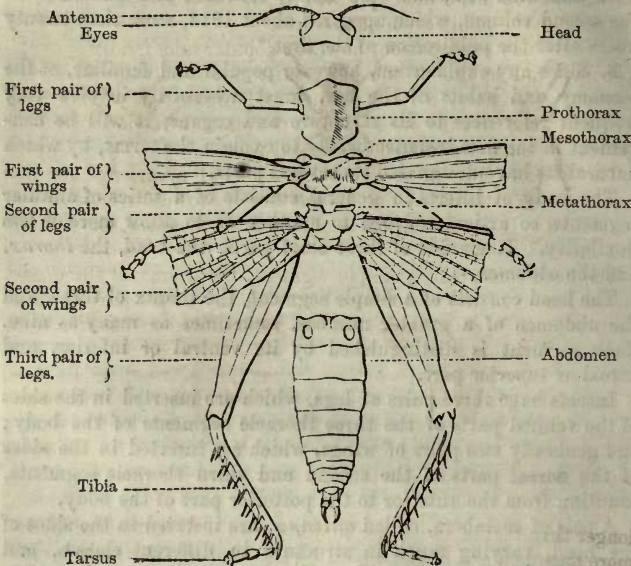


Fig. 1.

11. How numerous are the varieties of bees may be conceived, when it is stated that of bees found in Great Britain alone, Kirby in his Monograph has enumerated 220 species, and other more recent observers have increased the number to 250. The species, however, which by its commercial importance, as well as by its remarkable habits and social organisation, presents the greatest interest, is the Hive Bee, to which, therefore, we shall chiefly limit our notice.

12. The Hive bee belongs to what naturalists have denominated the perfect societies of insects. Each community of these insects consists of three orders of individuals distinguished by their number, their organisation, and the respective share they take in the common labour of the society. These are denominated severally the *queen* or sovereign, the males or *drones*, and the *workers;* the latter consisting of two classes, called the *wax-makers* and the *nurses.* A hive which contains as many as 50000 bees will have only one queen, and not above 2000 males.

13. The *queen* who, as her title implies, is the acknowledged

monarch of the hive, is distinguished from her subjects by conspicuous personal peculiarities. Her body, fig. 2, is considerably

Fig. 2.

Queen.

Fig. 3.

Drone.

Fig. 4.

Wax-maker.

Fig. 5.

Nurse, loaded with pollen.

Fig. 6.

Drone in flight, showing organs of fecundation.

longer than that of any of her subjects; she is distinguished by a more measured and majestic gait, by the comparative shortness of her wings, and the curvature of her sting. Her wings, which are strong and sinewy, are only half the length of her body, extending very little beyond the posterior limit of her thorax, while those of the drones, fig. 3, and the workers, fig. 4, cover the abdomen. Her legs are destitute of the brushes and baskets with which those of the workers are furnished. She has no occasion for these instruments of industry, since her exalted station exempts her from labour, all her wants being munificently provided for by her subjects. She is distinguished by her colour as much as by her form, the black of the dorsal part of her body being much brighter than that of the drones and workers, and the ventral parts and legs being of dark orange or copper-colour, the hue of the hinder being deeper than that of the other legs.

The queen, who is the only lady of the hive, enjoys the privilege of being followed by many hundred suitors in the persons of the drones. At the early age of two or three days she is marriageable, and it rarely happens that her royal decision is long postponed; and, indeed, if she were not favourably disposed for such an event, the anxiety of her numerous subjects would urge

her to it, for in no human monarchy are the hopes of succession so anxiously cherished as in the Empire of the Hive.

14. It must not be imagined, that because a lady is thus domesticated alone with so many hundred lovers, there is any the least degree of laxity in the morals of the society; on the contrary, although she is absolutely uncontrolled, and is courted by so many hundreds, her choice is strictly limited to one. A fine warm sunny day is selected for the nuptials, which are celebrated in the air. On the auspicious occasion, her majesty issuing from the hive followed by the multitude of her suitors, rises in the air, where she is encircled by the flight of the candidates for her favour. Here she makes her selection, but, alas! the felicity is brief, for the object of her choice never outlives the wedding-day. She is, however, not the less faithful to him, and never contracts a second marriage.

15. Though her majesty is thus left a widowed bride, in two days after the celebration of her nuptials and the loss of her lord, she commences to lay eggs from which a posthumous progeny of that lord, countless in number, are destined to issue. Of the hundreds of rejected suitors, a limited number emigrate with the successive swarms, which from time to time leave the overpeopled hive. Those which remain, being no longer useful to the community, become objects of general aversion, and are finally exterminated by a general massacre, as will presently be more fully explained.

16. During six or eight weeks the queen constantly lays eggs, from which working bees only are destined to issue. Chambers have been previously prepared for these, suitable to the future young ones, in form, size, and position, by the workers. In each of those cells the queen deposits a single egg.

At a later period her majesty begins to lay another kind of egg, from which males will issue. For these also special chambers have been provided by the careful workers, of suitable dimensions, being somewhat more roomy than those prepared for worker-eggs. The number of these male eggs and of the cells for their reception is incomparably less than those of the workers; less, in short, in the proportion in which the drone class is less numerous than that of the workers in the population of the hive.

17. In fine, the queen, sensible of her mortality, and moreover of the approaching state of superabundant population in the hive, lays a certain small number of royal eggs, from which as many princesses issue, who are severally destined to be candidates for the thrones of the colonies which are to emigrate, or to succeed to the throne of the hive itself, should the queen-mother, as often

happens, decide on abdicating and accepting the allegiance of one or other of the emigrating colonies.

18. Special chambers of exceptional form, position and magnitude have been previously prepared for these royal eggs by the provident workers. In these the princesses are reared and educated with extraordinary care, being fed with a peculiar food.

19. It is essential to the prosperity of the community, that the nuptials of the queen should not be postponed to a later period than the second day of her age, the consequence of such postponement being that her progeny would consist of a redundancy of drones. Thus, if the marriage be postponed till she is about a fortnight old, she will lay as many drone as worker-eggs, and if it be delayed until her age is three weeks, she will only lay drone eggs. How great a calamity such events must be in the apiarian economy will be understood, when it is considered that in a well-regulated society there ought to be about ten workers to each drone. The general duration of the life of a queen is from five to six years.

20. The males or drones, fig. 3, are less than the queen and larger than the workers, fig. 4. The extremity of the body is more velvety. The last segment being fringed with hair, extending over the tail, so as to be visible to the naked eye. They take no part whatever in the labours of the community, contribute nothing to the common stock, are idle, slothful, and cowardly, and, as if to render their extermination more easy to the industrious part of the population, nature has given them no sting. They make a louder buzz with their wings in flight, never exercise any industry, and are destitute of the baskets and other appendages with which the busy workers collect the materials of honey and wax.

The life of a drone does not exceed a few months, and he seldom dies a natural death. If he is honoured by the choice of the queen and elevated to the rank of king-consort, he dies on the very day of the nuptials. If he be among the hundreds rejected by her majesty, and do not emigrate with one or other of the swarms, being a useless and idle member of the community, he is massacred by the workers.

21. The workers, sometimes called neuters, are generally considered as sterile females. The number of these in each community is very variable, being seldom less than 12000, more generally amounting to 20000, and in hives where swarming is checked by affording abundance of room, the number may rise to 60000. They are the smallest members of the society, fig. 4, have a long flexible proboscis and legs of peculiar structure.

22. Among the wonders presented by the insect-world the *head* of the bee and its appendages command especial attention.

In common with insects generally, the chief parts of the mouth are, the *tongue*, the *jaws*, the *lips*, and the *throat* or œsophagus.

The jaws are each double, separated by a vertical division. Each pair opens, therefore, with a horizontal instead of a vertical movement like the human jaws. The pair of upper jaws are called *mandibles*, and the lower *maxillæ*. The upper lip is called the *labrum* and the lower the *labium*. The mouth is also supplied with two pairs of special organs called *palpi* or feelers, one pair attached to the lower lip and called *labipalpi*, and the other to the lower jaw and called *maxipalpi*.

23. In fig. 7, is given a magnified view of the buccal apparatus of the wild bee (*Anthophora retusa*),* the parts being indicated.

Fig. 7.

A less detailed view, also magnified, of the same apparatus of the hive-bee is shown in fig. 8.

Fig. 8.—Tongue of Hive bee (magnified).

* Milne Edwards.

A magnified view of the head of the drone is shown in fig. 9.

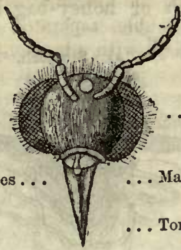


Fig. 9.—Head of a Drone (magnified).

The mandibles, or upper pair of jaws, in the workers are strong, horny and sharp. They are the tools with which it performs its various labours. Meeting over the other parts of the mouth, they are covered in front by the labrum or upper lip. The maxillæ, or lower jaws, on the contrary are pliable and leathery, and hold the objects upon which the insect works with its mandibles.

The tongue, which is long and endowed with great flexibility, is moved by a complex system of powerful muscles. When it is in a state of inaction, it is withdrawn within its sheaths, the end which protrudes beyond them being doubled up under the head and neck, the sheaths consisting of two pair of strong scales.

24. When the bee lights upon the blossom of a flower from which it desires to extract the nectar, it darts out its tongue from the sheaths that invest it, and having pierced the petals and stamina where the treasure is hidden, it inserts its tongue which moves about in every direction in virtue of its great flexibility and muscular power, and probes to the very bottom the floral cells, sweeping their surfaces and draining them to the last drop of their precious juice. Having thus collected the nectar upon the tongue, that organ being drawn back into the mouth, the liquid sweets are projected back into the pharynx, and thence into the throat or œsophagus.

Fig. 10.—Worker extracting nectar from a blossom.

25. It must be observed also, that the tongue is not only flexible but susceptible of inflation, so as to form a sort of bag,* in which

* Dr. Bevan on the Honey Bee, p. 298.

the nectar is collected preparatory to being transferred to the œsophagus.

26. The first stomach or honey-bag into which the nectar

Fig. 11.—Digestive apparatus of the Bee (magnified).

passes through the œsophagus,—which is a long and slender tube passing from the back of the mouth through the neck,—has the form of a Florence flask, and is composed of a material as transparent as glass. When filled it has the magnitude of a small pea. The honey received by it is partly regurgitated and deposited for general use in the cells of the comb, which will presently be described. The remainder which constitutes the food of the insect passes into the true stomach, and from thence into the intestines where it undergoes the process of digestion, the products of which are distributed through suitable tubes to all parts of the body for its nourishment.

27. Both the honey-bag and the stomach are susceptible of contraction, by which the food is thrown back from the former into the mouth as in ruminating animals, and from the latter into the intestines.

28. The antennæ are organs of great importance, upon the functions of which, however, naturalists are not fully agreed. It appears certain nevertheless, that they are not only tactile instruments of great sensitiveness, but are organs, by the signs, gestures, and mutual contact of which the bees communicate to each other their mutual wants, and convey information in many cases, some of which will be noticed hereafter, respecting the condition of the hive.

29. The flying-apparatus of the bee, as well as that of many other insects, far exceeds in power the instruments of flight with which the swiftest birds are furnished. To the anterior margin of the under wings are attached eighteen or twenty hooks, which when spread for flight (figs. 5, 6) lay hold of the posterior edges of the upper wings, so that the two wings on each side thus united act as a single wing.

30. The three pairs of legs are composed of several joints (fig. 1) articulated like those of the human arm, so as to give great mobility to the member. The lower joints of the two under pairs form brushes, the hairs of which are stiff and bristly, and set upon their inner surfaces. The farina which they collect from the stamina of flowers is swept off by these brushes, as well as by the hairs with which their abdomen and thorax are covered. This farina is afterwards by means of the maxillæ or jaws, and the feet of the anterior pair of legs, rolled into pellets and packed in a pair of spoon-shaped cavities or baskets, provided for that purpose and attached to the feet of the hindmost pair of legs. In this process the brushes, after disposing of their own collection of farina, sweep that flour also from the surface of the abdomen and thorax, and pack it in like manner in the baskets. The exterior of these baskets is smooth and glossy, and the interior lined with strong close hairs to retain the load in its place, and prevent its escape in flight.

Fig. 12.—Posterior leg of a worker.

It is worthy of remark that neither the queen nor the drones are supplied with this appendage. Since neither exercise any industry they would have no use for it.

31. Each foot terminates in two hooks, the points of which are opposed one to the other. By means of these the insects suspend themselves at will to the sides and roofs of their habitation, and hanging from each other form a living curtain in certain operations which will be presently noticed.

In the middle of each of these is placed the *sucker*, by which the insect is enabled to walk with facility on surfaces with its body downwards, as we see flies walk on ceilings. These suckers are little flexible cups, the edges of which are serrated so as to allow of their close application to any kind of surface. When closely applied, the air between the sucker and the surface is excluded, so that the body is attached to the surface by the pressure of the atmosphere. When the foot is to be detached from the surface, as in walking, the air is readmitted. This apparatus may be

easily seen, and its action observed, by inspecting with a microscope the feet of a fly walking on a pane of glass, the observer being on the side of the pane opposite to that on which the fly moves.

32. Besides the stomach and intestines, the abdomen of the queen and workers contains the sting and the apparatus connected with it, by which the venom which it pours into the wound is secreted, an instrument of offence supplied to these in common with many other species of four-winged insects. This formidable weapon of vengeance is established in its tail. All the insects which in common with the bee are supplied with a sting, belong to the order hymenoptera or membrane-winged. This weapon consists of two darts finer than a hair, which lie in juxtaposition, being barbed on the outer sides, but so minutely that the points can only be seen with the microscope. These darts move in the groove of a strong sheath, which is often mistaken for the sting itself. When the dart enters the flesh, a drop of subtle venom, secreted by a peculiar gland, is ejected through the sheath and deposited in the wound. This poison produces considerable tumefaction, attended with very acute pain.

The posterior extremity of the body of a worker with the sting protruded is shown in fig. 13.

Fig. 13.—Posterior extremity of the body of a worker with the sting protruded.

Fig. 14.—The same slightly magnified, showing the venom-bag.

The sheath of the sting, also called the ovipositor, consists, according to Dr. Bevan, of a long tube, or rather of several tubes, which pass one into another like those of a telescope. The muscles by which the sting is propelled, though too minute to be seen without the microscope, have, nevertheless, sufficient power to drive the sting to the depth of the twelfth of an inch into the thick cuticle of a man's hand. The sting is articulated by thirteen scales to the posterior extremity of the body, and at its root are the pair of glands, one of which appears in fig. 14, in which the poison

is secreted. These glands, communicating by a common duct with the groove formed by the junction of the lower parts of the barbed sting, send the venomous liquid through that groove into the wound. On each dart there are four barbs. When the insect intends to sting, one of these piercers having its point a little longer, or more in advance than the others, is first darted into the flesh, and being fixed there by its barb, the other strikes in also; and they alternately penetrate deeper and deeper, till they acquire a firm hold of the flesh with the barbed hooks, and then follows the sheath, enclosing and conveying the poison into the wound. The action of the sting thus, as Paley observed, affords an example of the union of chemical and mechanical principles: of chemistry, in respect to the venom; and of mechanism, in the motion into the flesh. The machinery would have been comparatively useless, had it not been for the chemical process by which in the body of the insect honey is converted into poison; and, on the other hand, the poison would have been ineffectual without an instrument to wound, and a syringe to inject it.

In consequence of the barbed form of the sting, and the strong hold it takes on the flesh, the bee can seldom withdraw it, and in detaching herself from the part stung she generally leaves behind her not only the sting itself, but the venom-bag and a part of her intestines. Swammerdam mentions a case in which even the stomach of the insect was torn from the abdomen in detaching herself, so that in most cases her life is the sacrifice for the gratification of her vengeance.

Although the bee, except in certain cases to be mentioned hereafter, uses its sting only in defence, or for vengeance, when molested, it is sometimes found that it manifests an antipathy to particular individuals, whom it attacks and wounds without provocation.

33. The organs of fecundation and reproduction are also contained in the abdomen. Those of the drone are represented on a magnified scale in fig. 15. They correspond in their functions to those of the superior animals.

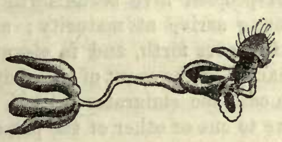


Fig. 15.—Apparatus of fecundation of the drone.

The organs of reproduction of the queen, which are objects of considerable interest, are shown on a magnified scale in fig. 16.

34. We have already stated that the king-consort never survives the bridal day. As this does not affect the conjugal fidelity

Fig. 16.—Ovaries of the queen and their appendages.

of her majesty, who never allows a successor to her departed lord, so neither does it impose any limit to the posthumous offspring which she bears to him. Small as are the ovaries, or egg organs, which are shown highly magnified in fig. 16, her majesty, according to Huber, generally produces from them abcut 12000 eggs in the short interval of two months, being at the average rate of 200 per day.

Although her majesty does not continue so prolific during the remainder of her life, she nevertheless gives birth to a progeny enormous in number. The number of eggs deposited by her in the cells in the months of April and May is, as above stated, about 12000. According to Schirach, a prolific queen will lay in a season—that is, from April to October inclusive—from 70000 to 100000 eggs. This amazing power of reproduction is not exerted uniformly during the season. There are two fits, so to speak, of fruitfulness. The first in April and May; the second, in August and September, with an interval of comparative repose in July. This immense increase of population, rendering emigration indispensable, the over-peopled hive sends forth swarm after swarm so fast as the young arrive at maturity; and with each swarm one of the princesses goes forth, and is elevated to the throne of the new colony, except in the event of the abdication of the queen-mother, in which case she emigrates herself, resigning the sovereignty of the hive to one or other of the princesses.

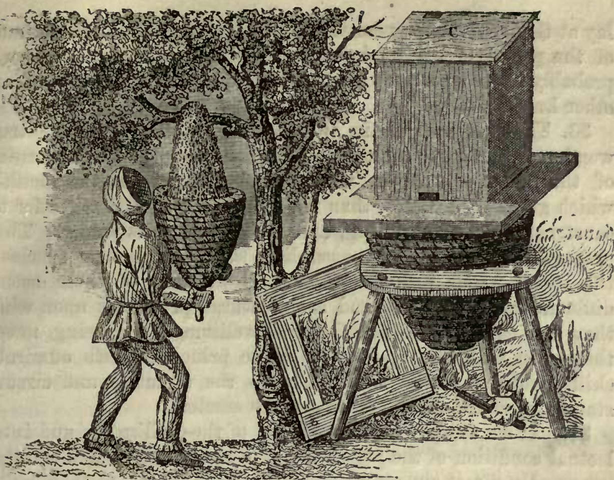


Fig. 76.—Hiving a swarm.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER II.

35. This fecundity not anomalous.—36. Bee architecture.—37. Social condition of a people indicated by their buildings.—38. This test applied to the bee. — 39. Individual and collective habits. — 40. Solitary bees.—41. Structure of their nests.—42. Situation of nests. — 43. Anthidium manicatum. — 44. Expedient for keeping nest warm.—45. Clothier bee.—46. Carpenter bee.—47. Mason bee.—48. Expedient to protect the nest.—49. Upholsterer bee.— 50. Hangings and carpets of her rooms.—51. Leaf-cutter bees.—52. Method of making their nest.—53. Process of cutting the leaves.—54. Hive-bee.—55. Structure of the comb.—56. Double layer of cells.—57. Pyramidal bases.—58. Illustrative figures.—59. Single cells.—60. Combination of cells.—61. Great advantages of hexagonal form.—62. Economy of space and material.—63. Solidity of structure.—64. Geometrical problem of the comb solved.—65. Expedient to secure the sides and bases of the cells.

35. The prodigious fecundity of the queen of the bees is by no means an anomaly in the insect world. The female of the white ants produces eggs at the rate of one per second, or 3600 per hour, or 86400 per day. Now, although this insect certainly does not

lay at this rate all the year round, yet, taking the lowest estimate of the period of her reproduction, the number of her young will probably exceed not only that of the queen bee, but that of any other known animal.*

36. There is nothing in the economy of the bee more truly wonderful, nor more calculated to excite our profound veneration of the beneficent power, which conferred upon it the faculties which guide its conduct, than the measures which it takes for the construction of its dwelling, and for those of its young. These processes are very various, according to the particular species of the insect which executes them. Now, most of these species differ in the mechanical and architectural principles upon which they base the construction of their dwellings, all agreeing, nevertheless, in this, that they select those principles with admirable skill, adapting them in all cases to the situation and circumstances in which their habitations are erected.

37. If we would form an estimate of the civilisation and intellectual condition of the population of a newly-discovered country, we usually direct our attention, as Kirby observes, to their buildings and other examples of architectural skill. If we find them like the wretched inhabitants of Van Diemen's land, without other abodes than natural caverns, or miserable penthouses of bark, we at once regard them as ignorant and unhumanised. If, like the South Sea islanders, they live in houses of timber thatched with leaves, and supplied with various utensils, we place them much higher in the scale. But when we discover a nation inhabiting towns like the ancient Mexicans, consisting of stone houses regularly arranged in streets, we do not hesitate to pronounce them advanced to a considerable point in civilisation.

If, moreover, it be found that each building has been constructed upon the most profound mathematical principles, so that the materials have been applied under such conditions as ensure the greatest degree of strength, combined with the greatest degree of lightness; and that, while the internal apartments display the most beautiful symmetry, they also afford the greatest capacity which a given amount of materials can admit, we at once arrive at the conclusion that such a population must have arrived not alone at the highest degree of civilisation, but at the highest point in the advancement of the sciences.

38. If we were to affirm that all this may be said with the most rigorous truth of many varieties of the bee, and above all of the common hive-bee, we might be suspected of being merely excited by that enthusiasm so common with those, who devote

* See Tract on the White Ants.

themselves exclusively to one particular pursuit. We must, nevertheless, leave the reader to judge how far such a statement is chargeable with the exaggeration of enthusiasm, when he shall have duly pondered upon all that we shall explain to him in the following pages; and if, perchance, his wonder be raised to the point of incredulity, that sentiment will be repressed when he remembers, *who taught the bee!*

39. Bees, like the human race, sometimes exercise their industry individually and sometimes collectively. Their habitations also are sometimes constructed exclusively for their young, and may be called *nests* rather than *dwellings*. This is more especially the case with solitary insects. In the case of social bees, which live together in organised communities, the habitations are generally adapted as well for the members of the colony themselves, as for their progeny.

40. The operations of these solitary insects, though exhibiting, as will presently appear, marvellous skill, are infinitely inferior to those of the social bees. We shall, therefore, first notice the more simple labours of the former.

41. Among the most inartificial structures executed by the solitary species, are the habitations of the *colletes succinctæ*, *fodiens*, &c. The situation chosen in these cases is either a bank of dry earth, or the cavities of mud walls. A cylindrical hole pierced in a horizontal direction about two inches in length is first produced. The bee makes in this three or four thimble-shaped cells, each of which is about a sixth of an inch in diameter and half an inch long, fitting one into another like thimbles. The materials of these cells is a silky membrane resembling gold-beater's leaf, but much finer, and so very thin and transparent that the form and colour of any enclosed object can be seen through it. This material is secreted by the insect. When the first of these cells is completed, the insect deposits in it an egg and fills it with a pasty substance, which is a mixture of pollen and honey. When this is done she proceeds to form the second cell, inserting its end in the mouth of the first as above described, and in like manner lays an egg in it and deposits with it a like store of food for the future young. This goes on until the cylindrical hole receives three or four cells which nearly fill it. The bee then carefully stops up the mouth of the hole with earth.

42. The situations in which these simple nests are placed are very various. They are not only found as above stated in banks of earth and mud walls, and the interstices of stone walls, but often also in the branches of trees. Thus a series of them was found by Grew in the pith of an old elder branch.

43. Some varieties of the bee, such as the *anthidium manicatum*, dispense with the labour of boring the cylindrical holes above

described, and avail themselves of the ready-made cavities of trees, or any other object which answers their purpose. Kirby mentions the example of nests of this kind found by himself and others, constructed in the inside of the lock of a garden-gate.

44. A proceeding has been ascertained on the part of these insects in such cases, which it is extremely difficult to ascribe to mere instinct, independent of some intelligence. Wherever the nest may be constructed, the due preservation of the young requires that until they attain the perfect state, their temperature should be maintained at a certain point. So long as the material surrounding their nest is a very imperfect conductor of heat, as earth or the pith of wood is, the heat developed by the insect, being confined, is sufficient to maintain its temperature at the requisite point. But if, perchance, the mother-bee select for her nest any such locality as that of the lock of a gate, the metal, being a good conductor of heat, would speedily dissipate the animal heat developed by the insect, and thus reduce its temperature to a point incompatible with the continuance of its existence. How then does the tender mother, foreseeing this, and consequently informed by some power of the physical quality peculiar to the metal surrounding the nest, provide against it? How, we may ask, would a scientific human architect prevent such an eventuality? He would seek for a suitable material which is a non-conductor of heat and would surround the nest with it. In fact the very thing has occurred in a like case in relation to steam-engine boilers. The economy of fuel there rendered it quite as necessary to confine the heat developed in the furnace, as it is to confine that which is developed in the natural economy of the pupa of the bee. The expedient therefore resorted to is to invest the boiler in a thick coating of a sort of felt, made for the purpose, which is almost a non-conductor of heat. A casing of sawdust is also used in Cornwall for a like purpose. By these expedients the escape of heat from the external surface of the boiler is prevented.

45. The bee keeps its pupa warm by an expedient so exactly similar, that we must suppose that she has been guided either by her own knowledge, or by a power that commands all knowledge, in her operations. She seeks certain woolly leaved plants, such as the stachys lanata or the agrostemma coronaria, and with her mandibles scrapes off the wool. She rolls this into little balls, and carrying it to the nest, sticks it on the external surface by means of a plaster, composed of honey and pollen, with which she previously coats it. Thus invested, the cells become impervious to heat, and consequently all the heat developed by the little animal is confined within them.

This curious habit of swathing up its pupa in a kind of warm blanket has given to these species the name of *clothiers*.

46. Another class of bees has acquired the name of *carpenters*, from the manner in which they carve out their nest in wood-work. This bee, which is represented in fig. 17, and of which the nest is shown in fig. 18, having been already described in our Tract on Instinct and Intelligence (72), need not be noticed further here.

Fig. 17.—The Carpenter Bee.

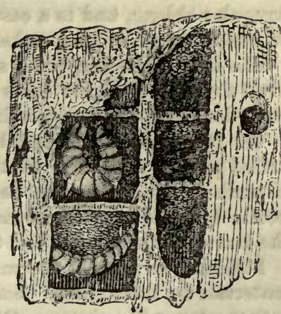


Fig. 18.—Nest of the Carpenter Bee.

47. Another class of this insect has acquired the name of *masons*, from the circumstance of building their nests of a sort of artificial stone. The situation selected is usually a stone wall, having a southern aspect, and sheltered on either side by some angular projection. The situation being decided upon, the mother-bee proceeds to collect the materials for the mansion, which consist of sand, with some mixture of earth. These she glues together, grain by grain, with a cement composed of viscid saliva, which she secretes. Having formed this material into little masses, like the grains of small shot, she transports them with her mandibles to the place where she has laid the foundation of her mansion.

With a number of these masses, united together by an excellent cement secreted by her organs, she first lays the foundation of the building. She next raises the walls of a cell about an inch in length, and half an inch broad, resembling in form a thimble. In this she deposits an egg, fills it with a mixture of pollen and honey, in the same manner as described in the former case, and after carefully covering it in, proceeds to the erection of a second building of the same kind, which she furnishes in the same manner, and so continues until she has completed from four to eight.

These cells are not placed in any regular order; some are

parallel, others perpendicular, and others inclined to the wall at different angles. The whole mass is consolidated by filling up the irregular intersticial spaces between the cells, with the same material as that of which the walls are built. After this has been accomplished, the whole is covered up with coarser grains of sand.

The nest when thus finished resembles a mass of solid stone, so hard as to be cut with much difficulty by a knife. Its form is an irregular oblong, and to a casual observer presents the appearance of a mere splash of mud rather than that of a regular structure.

The insects are sometimes so sparing of their labour, that they avail themselves of old nests when they can find them, and often have desperate combats to seize and retain possession of them.

48. It might be imagined that nests so solidly constructed would afford perfect protection to the young from its enemies; such is nevertheless not found to be the case. The ichneumon and the beetle both contrive occasionally to deposit their eggs in the cells, the larvæ of which never fail to devour their inhabitants.

Different varieties of the masons select different situations and materials for their nests. Some use fine earth, which they make into mortar with gluten. Others mix sandy earth with chalk. Some construct their nests in chalk-pits, others in the cavities ot large stones, while others bore holes for them in rotten wood. Wherever placed they endeavour to conceal them, by plastering or covering them with some material different from that of which the nest is constructed. Thus one species surrounds its nest with oak-leaves glued to its surface. M. Goureau mentions the case of a bee that employed an entire day, in arranging blades of grass about two inches long, in the form of the top of a tent over the mouth of its nest. A case of this sort was also observed by Mr. Thwaites, who saw a female for a considerable time collecting small blades of grass, which she laid over the empty shell of a snail in which she had located her nest.

49. The name of *upholsterers* has been given by Kirby to certain species of bees, who, having excavated their nest in the earth, hang its walls with a splendid coating of flowers and leaves. One of the most interesting of these varieties is the *megachile papaveris*, which has been described by Reaumur. It chooses invariably for the hangings of its apartments the most brilliant scarlet, selecting as its material the petals of the wild poppy, which the insect dexterously cuts into the proper form.

50. Her first process is to excavate in some pathway a burrow cylindrical at the entrance, but enlarged as it descends, the depth being about three inches. After having polished the walls, she next flies to a neighbouring field, where she cuts out the oval

parts of the poppy blossoms, and seizing them between her hind legs returns with them to her cell. Sometimes it happens that the flower from which she cuts these, being but half blown, has a wrinkled petal. In that case she spreads out the folds, and smoothes away the wrinkles, and if she finds that the pieces are too large to fit the vacant spaces on the walls of her little room, she soon reduces them to suitable dimensions, by cutting off all the superfluous parts with her mandibles. In hanging the walls with this brilliant tapestry she begins at the bottom, and gradually ascends to the roof. She carpets in the same manner the surface of the ground round the margin of the orifice. The floor is rendered warm sometimes by three or four layers of carpeting, but never has less than two.

Our little upholsterer having thus completed the hangings of her apartment, fills it with a mixture of pollen and honey to the height of about half an inch. She then lays an egg in it, and wraps over the poppy lining, so that even the roof may be furnished with this material. Having accomplished this she closes the mouth of the nest.*

51. It is not every insect of this class which manifests the same showy taste in the colours of their furniture. The species called *leaf-cutters* hang their walls in the same way, not with the blossoms but the leaves of trees, and more particularly those of the rose-tree. They differ also from the upholsterer, described above, in the external structure of their nests, which are formed in much longer cylindrical holes, and consist of a series of thimble-shaped cells, composed of leaves most curiously convoluted. We are indebted likewise to Reaumur for a description of the labours of these.

52. The mother first excavates a cylindrical hole in a horizontal direction eight or ten inches long, either in the ground or in the trunk of a rotten tree, or any other decaying wood. She fills this hole with six or seven thimble-shaped cells, composed of cut leaves, the convex end of each fitting into the open end of the other. Her first process is to form the external coating, which is composed of three or four pieces of larger dimensions than the rest, and of an oval form. The second coating consists of portions of equal size, narrow at one end, but gradually widening towards the other, where the width equals half the length. One side of these pieces is the serrated edge of the leaf from which it was taken, which, as the pieces lap over each other, is kept on the outside, the edge which was cut being within.

The little animal next forms a third coating of similar material,

* Reaumur, vi. 139 to 148.

the middle of which, as the most skilful workman would do in a like case, she places over the margins of those that form the first side, thus covering and strengthening the junctions by the expedient which mechanics call a break-joint. Continuing the same process she gives a fourth and sometimes a fifth coating to her nest, taking care at the closed end or narrow extremity of the cell, to bend the leaves so as to form a convex termination.

After thus completing each cell, she proceeds to fill it to within the twentieth of an inch of the orifice with a rose-coloured sweetmeat made of the pollen collected from thistle blossoms mixed with honey. Upon this she lays her egg, and then closes the orifice with three pieces of leaf, one placed upon the other, concentrical and also so exactly circular in form, that no compasses could describe that geometrical figure with more precision. In their magnitude also they correspond with the walls of the cell with such a degree of precision, that they are retained in their situation merely by the nicety of their adaptation.

The covering of the cell thus adapted to it being concave, corresponds exactly with the convex end of the cell which is to succeed it, and in this manner the little insect prosecutes her maternal labours, until she has constructed all the cells, six or seven in number, necessary to fill the cylindrical hole.

53. The process which one of these bees employs in cutting the pieces of leaf that compose her nest, is worthy of attention. Nothing can be more expeditious, and she is not longer about it than one would be in cutting similar pieces with a pair of scissors. After hovering for some moments over a rose-bush, as it were to reconnoitre the ground, the bee alights upon the leaf which she has selected, usually taking her station upon its edge, so that its margin shall pass between her legs. She then cuts with her mandibles, without intermission, in such a direction as to detach from the leaf a triangular piece. When this hangs by the last fibre, lest its weight should carry her to the ground, she spreads her little wings for flight, and the very moment the connection of the part thus cut off with the leaf is broken, she carries it off in triumph to her nest, the detached portion remaining bent between her legs in a direction perpendicular to her body. Thus, without rule or compass, do these little creatures measure out the material of their work into ovals, or circles, or other pieces of suitable shapes, accurately accommodating the dimensions of the several pieces of these figures to each other. What other architect could carry impressed upon the tablet of his memory such details of the edifice which he has to erect, and destitute of square or plumb-line, cut out his materials in their exact dimensions without making a single mistake or requiring a single subsequent correc-

tion? Yet this is what the little bee invariably does. So far are human art and reason surpassed by that instruction which the insect receives from its Divine Creator.*

54. But of all the varieties of this insect, that of which the architectural and mechanical skill is transcendently the most admirable, is the *hive-bee.* The most profound philosopher, says Kirby, equally with the most incurious of mortals, is filled with astonishment at the view of the interior of a bee-hive. He beholds there a miniature city. He sees regular streets, disposed in parallel directions, and consisting of houses constructed upon the most exact geometrical principles, and of the most symmetrical forms. These buildings are appropriated to various purposes. Some are warehouses in which provisions are stored in enormous quantities. Some are the dwellings of the citizens, and a few of the most spacious and magnificent are royal palaces. He finds that the material of which this city is built, is one which man with all his skill and science cannot fabricate, and that the edifices which it is employed to form are such that the most consummate engineer could not reproduce, much less originate; and yet this wondrous production of art and skill is the result of the labour of a society of insects so minute, that hundreds of thousands of them do not contain as much ponderable matter, as would enter into the composition of the body of a man. *Quel abîme aux yeux du sage qu'une ruche d'abeilles! Quelle sagesse profonde se cache dans cet abîme! Quel philosophe osera le sonder!* Nor has the problem thus solved by the bee, yet been satisfactorily expounded by philosophers. Its mysteries have not yet been fathomed. In all ages naturalists and mathematicians have been engrossed by it, from Aristomachus of Soli and Philiscus the Thracian, already mentioned, to Swammerdam, Reaumur, Hunter, and Huber of modern times. Nevertheless the honey-comb is still a miracle which overwhelms our faculties.†

55. A honey-comb, when examined, is found to be a flattish cake with surfaces sensibly parallel, each surface being reticulated with hexagonal forms of the utmost regularity. No geometrician could describe the regular hexagon with greater precision than is here exhibited.

It is proved in geometry that there are only three regular figures, which, being joined together at their corners, will so fit each other as to leave no unoccupied spaces between them. These figures are the square, the equilateral triangle, and the regular hexagon. Four squares united by one of their angles will fill all

* Reaumur, vi. 971; Kirby, Int., i. 377.
† Kirby, i. 410.

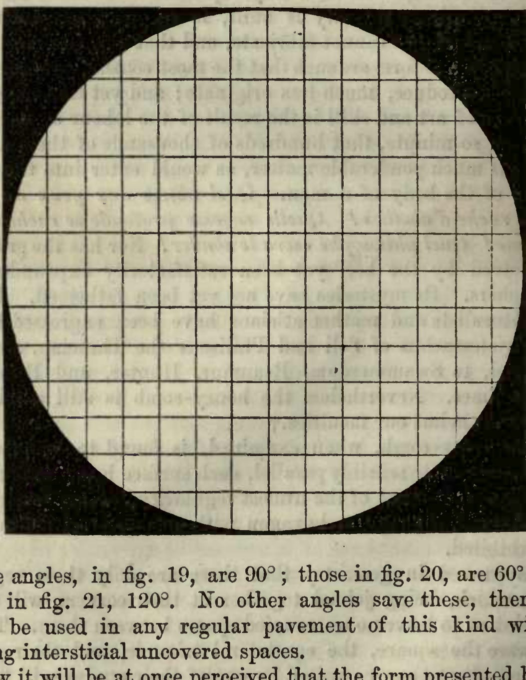
the surrounding space, and any number of squares may thus be combined so as to cover a surface like a mosaic pavement without leaving any intermediate unoccupied spaces.

In like manner six equilateral triangles will have a like property, and in fine, three regular hexagons being similarly united at one of their corners, will in like manner completely occupy the surrounding space.

Since no other regular geometrical figure possesses this property, it follows that a regular mosaic pavement must necessarily be composed of one or other of these figures.

Fig. 19 represents such a pavement composed of squares; and fig. 20, one composed of equilateral triangles; and in fine, fig. 21, one composed of regular hexagons.

Fig. 19.

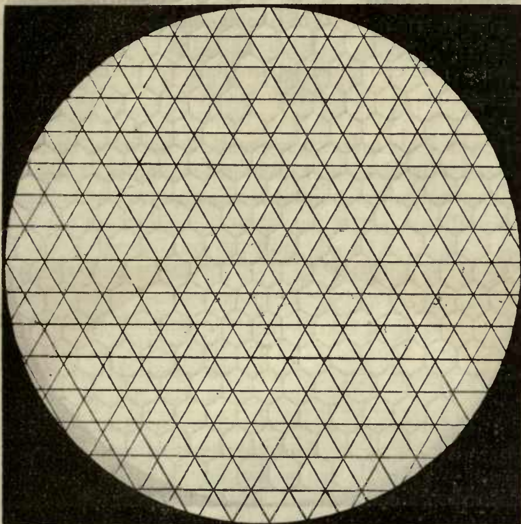


The angles, in fig. 19, are 90°; those in fig. 20, are 60°; and those in fig. 21, 120°. No other angles save these, therefore, could be used in any regular pavement of this kind without leaving intersticial uncovered spaces.

Now it will be at once perceived that the form presented by the surface of a honey-comb is that of an hexagonal pavement. We shall presently see why the bee has selected this in preference to either of the other possible forms.

56. On further examining the comb, it will be found that the hexagonal spaces presented by its surface are the mouths of so

Fig. 20.



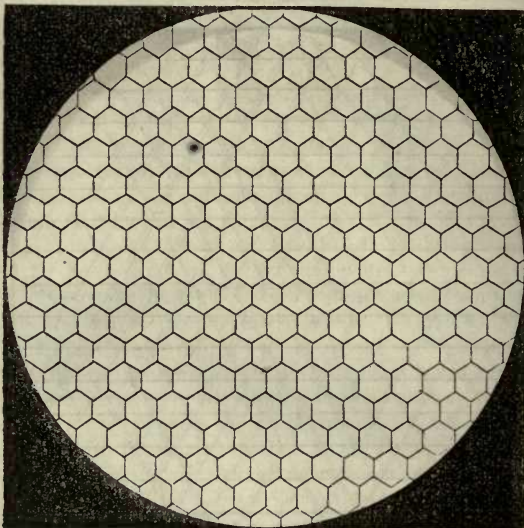
many hexagonal tubes which are filled with honey. If any of these be empty, it will be seen that the depth of these tubes is half the thickness of the comb.

57. It appears therefore that the honey-comb is a combination of hexagonal tubes, placed in juxtaposition, the angles of the hexagon being fitted into each other like the stones of a mosaic pavement; that there are two systems of such tubes, meeting in the middle of the thickness of the comb, their mouths being presented outwards on both sides, and consequently their bases resting against each other.

If by the dissection of the comb, the forms of their bases be examined, they will be found to consist, not as might be at first supposed of plane regular hexagons, which would be the case if they were plane surfaces at right angles to the tube; they will be found, on the other hand, to have the form of pyramids, each of which is composed of three regular lozenges united together at their edges, so as to form an apex; this apex being pointed always towards the opposite side of the comb. The pyramidal base is

thus a geometrical figure, having as much regularity as the hexagonal tube, of which it forms the termination, but constructed

Fig. 21.



on a totally different principle. The angles of the lozenges, which form its sides, are one obtuse and the other acute; and these pyramidal bases of the cells, on one side of the comb, fit into corresponding cavities, made by the similar pyramidal bases of the cells, on the other side of the comb, so as to leave no intermediate unoccupied space.

58. Without the aid of perspective figures, and even with such aid, without some effort of imagination on the part of the reader, it would be impossible to convey a clear notion of this part of the structure of the honey-comb, and yet without such a clear notion it would be totally impossible to appreciate the admirable results of bee industry. We have, therefore, attempted to represent in figs. 22 and 23, the bases of four contiguous cells seen from the inside and from the outside. In fig. 22 is presented an inside view of the bases of three adjacent cells, *a a a*. It must be observed that *a a a* are here intended to represent angular cavities, each formed by the junction of three lozenge-shaped planes, such as have been just described. Now it will be seen, that as a necessary consequence of this juxtaposition, a figure will be formed at *b*, by three lozenge-

shaped planes, one belonging to each of the three bases, *a a a*, and that this, instead of being hollow on the side presented to

Fig. 22.

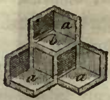
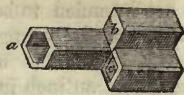


Fig. 23.

Fig. 24.

Fig. 25.



the eye, will be hollow on the opposite side, which is turned from the eye, and will there form an angular cavity precisely similar and equal to the cavities *a a a*, which are turned towards the eye. Now this cavity, which is thus turned to the opposite side, is the base of one of the cells on the other side of the comb. In fig. 23 we have presented a view of the combination as it would be seen on the other side. In this case, the angular cavity darkly shaded in the middle of the figure, is the angular projection, *b*, in fig. 22, seen on the other side; and the three angular projections which surround it, jutting forward towards the eye, are the three angular bases, *a a a*, fig. 22, seen on the other side.

59. A perspective view of a single hexagonal tube or cell, with its pyramidal base, is shown in fig. 24.

The manner in which the hexagonal cells are united base to base to form the comb, is shown in perspective in fig. 25, where *a* is the open mouth of the tube, and *b c* the lozenge-shaped planes, forming the bases of the opposite tubes. The same is shown in section in fig. 26.

Fig. 26.

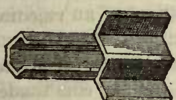


Fig. 27.

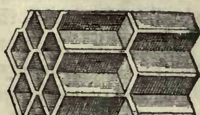
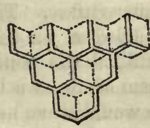


Fig. 28.



60. Several hexagonal cells are shown in their natural juxtaposition, placed base to base, as they form the comb, in fig. 27, and a perspective view of their pyramidal bases is given in fig. 28.

Nothing can be more surprising than this production of such an insect, when regarded as a piece of scientific engineering. The substance which comprises it being one secreted by the bees in limited quantity, it was of the greatest importance in its use, that a material so scarce should be applied so as to produce the greatest possible result, with the smallest possible quantity of the material. The problem, therefore, which the bee had to solve

was, with a given quantity of wax, to construct a combination of similar and equal cells of the greatest aggregate capacity, and such as to occupy the available space in the hive to the greatest possible advantage. The form and magnitude of the cells must necessarily have been adapted to those of the bee itself, because these cells are intended to be the nests in which the eggs are laid and hatched, and the young bee raised to its state of maturity.

The body of the bee being oblong, and measuring about six-tenths of an inch in length by two-tenths in diameter, cylindrical tubes of corresponding dimensions would have answered the purpose; but such tubes could not be united together in juxtaposition without either a great waste of wax or great deficiency of strength, since, when placed in contiguity, they would leave between them empty spaces of considerable magnitude, which, if left unoccupied, would render the structure weak, and if filled with wax, would have the double disadvantage of giving needless and injurious weight to the comb, and involving the waste of a quantity of a scarce and precious material, greater than all that would be necessary to form the really useful part of the comb.

61. From what has been explained it will be understood that, to form a combination of tubular cells without interstices, the choice of the bee was necessarily limited to the three figures already mentioned—the equilateral triangle, the square, and the regular hexagon. The equilateral triangle would be attended with the disadvantage of a great waste of both space and material; for if its dimensions were sufficient to afford easy room to the body of the bee, a large space would be wasted at each of the angles, towards which the body of the bee could never approach.

A like disadvantage, though less in degree, would have attended square tubes. The bee, therefore, with the instinct of an engineer, decided on the third form, of the regular hexagon, which at once fulfilled the conditions of a sufficiently near adaptation to the form of its own body, and the advantage of such a combination as would leave neither waste space nor loss of material.

62. In the structure of the comb there is still another point worthy of attention. It might naturally have been expected that it would be composed of a single layer of cells, one side presenting the mouth, and the other the pyramidal base; but if this had been the course adopted, the side consisting of the pyramidal bases would be an extensive surface, upon which the industry of the bee would have no occupation, and the space in the hive to which such surface would be presented would, therefore, be so much space wasted. Instead, therefore, of constructing the comb of a single layer of cells, the bees judiciously make it of a

double layer, the pyramidal bases of each layer being placed in contact with each other.

It might also have been expected that these bases would have received the most simple form of plane surfaces, so that the side of each layer occupied by them would be a uniform plane; and these planes resting in contact would form the comb; but to this there would be several objections. In the first place, the capacity of the comb would be less; the bases of the cells, placed in contact, would be liable to slip one upon the other; and if the cells had a common base, they would have less strength; but independently of this, the bee itself tapers towards its posterior extremity, and a cell with a flat bottom having no corresponding tapering form would be little adapted to its shape, and would involve a consequent waste of space. The bee avoids this disadvantage by giving the bottom of the cell the shape of a hollow angular pyramid, into the depth of which the tapering posterior extremity of the insect enters.

63. There is another advantage in this arrangement which must not be overlooked. The pyramidal bases of each layer of cells, placed in juxtaposition by reciprocally fitting each other, so that the angular projections of each are received into the angular cavities of the other, are effective means of resisting all lateral displacement.

64. Pyramidal bases, however, might have been given to the cells in a great variety of ways, which would have equally served the purposes here indicated; but it was essential, on grounds of economy, that that form should be selected which would give the greatest possible capacity with the least possible material. On examining curiously the form of the lozenges composing the pyramidal bases of the cells, Maraldi found by accurate measurement that their acute angle measured 70° 32′, and consequently their obtuse angle 109° 28′. Magnitudes so singular as these, invariably reproduced in all the regular cells, could scarcely be imagined to have been adopted by these little engineers without a special purpose, and Reaumur accordingly conjectured that the object must have been the economy of wax.

Not being himself a mathematician sufficiently profound to solve a problem of this order, he submitted to M. Koenig, an eminent geometer of that day, the general problem to determine the form which ought to be given to the pyramidal bottom of an hexagonal prism, such as those constituting the cones, so that with a given capacity, the least possible material would be necessary for the construction. The problem was one requiring for its solution the highest resources to which analytical science had then attained. Its solution, however, was obtained, from which it

appeared that the proper angles for the lozenges would be 70° 34′ for the acute, and consequently 109° 26′ for the obtuse angle. Here are then in juxtaposition the result of the labours of the geometer and the bee.

	ACUTE ANGLE.	OBTUSE ANGLE.
Geometer	70° 34′	109° 26′
Bee	70° 32′	109° 28′

We leave the reader to enjoy the contemplation of these numbers without one word more of comment.

65. "Besides the saving of wax effected by the form of the cells, the bees adopt another economical plan suited to the same end. They compose the bottoms and sides of wax of very great tenuity, not thicker than a sheet of writing-paper; but as walls of this thickness at the entrance would be perpetually injured by the ingress and egress of the workers, they prudently make the margin at the opening of each cell three or four times thicker than the walls. Dr. Barclay discovered that though of such excessive tenuity, the sides and bottom of each cell are actually double, or in other words, that each cell is distinct, separate, and in some measure an independent structure, agglutinated only to the neighbouring cells; and that when the agglutinating substance is destroyed, each cell may be entirely separated from the rest. This, however, has been denied by Mr. Waterhouse, and seems inconsistent with the account given by Huber, hereafter detailed; but Mr. G. Newport asserts, that even the virgin-cells are lined with a delicate membrane." *

* Kirby, i. p. 412.

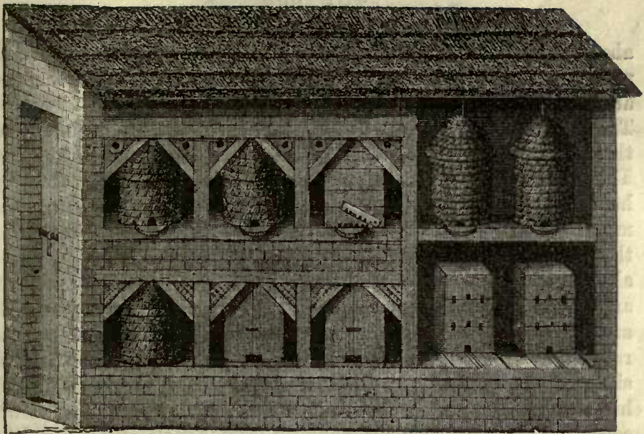


Fig. 55.—COVERED APIARY.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER III.

66. Drone cells and worker cells.—67. Store cells.—68. Construction of combs.—69. Wax-makers also produce honey.—70. First operation of the wax-makers.—71. Process of the foundress.—72. Kneading the wax.—73. Formation of first wall.—74. Correction of mistakes.—75. Dimensions of first wall.—76. Operations of the nurses.—77. Bases of cells.—78. Wax-makers resume their work.—Completion of pyramidal bases.—79. Pyramidal partition.—80. Formation of cells.—81-82. Arrangement of combs.—83. Sides not parallel.—84. Process not merely mechanical.—85-86. Process of construction.—87. Labour successive.—88. Dimensions of cells.—89. Their number.—90. Bee-bread.—91. Pap for young.—92. Food adapted to age.—93. Transformation.—94. Humble-bees—females.—95. Their nursing workers.—96. Transformation.—97. How the temperature of the cocoons is maintained.—98. Anecdote related by Huber.—99. Remarkable care of the nurses.—100. Heat evolved in respiration by the hive-bee—101. Cross alleys connecting the streets.—102. First laying of the queen in Spring.—103. Her royal suite.—104. The eggs.

66. Since the population of the hive is composed, as already explained, of different classes of individuals having different stature, and since one of the purposes of the cells is to be their

abode from the time they issue from the egg until they attain maturity, it follows that the capacity of the cells, or such of them as are thus appropriated, must be subject to a corresponding difference. The cells of the workers will therefore be less in magnitude than those of the drones, and these last much less than the royal cells. The comb therefore consists of different parts reticulated by hexagons of different magnitudes, the smaller ones being the mouths of the cells appropriated to the workers, and the larger those of the cradles of the drones. As to the royal cells they differ altogether from the others, not only in capacity, but also in position and form. As already explained, the general forms of the cells are hexagonal tubes, with pyramidal bases, and open mouths ranged horizontally, their axes being at right angles to the flat sides of the comb. The comb itself is placed vertically in the hive, and the royal cells which are large and pear-shaped are cemented to its lower edges, hanging from it vertically like stalactites from the roof of a cavern. Although there be but one queen in each hive, she produces, nevertheless, three or four or more, and sometimes even as many as thirty or forty royal eggs. The princesses which issue from these, are destined to be the queens of the successive swarms which the hive sends forth.

67. The cells which are appropriated exclusively to the storage of honey and pollen, are similar in form and position to those appropriated to the young drones and workers, but are greater in length, and this length the bees vary according to the exigencies of their store of provisions. If more of these result from their labours than the cells constructed can contain, and there is not time or space for the construction of more cells, they lengthen the honey-cells already made by cementing a rim upon them. They sometimes also use for storage, cells which have already been occupied by young drones or workers, which, having attained their state of maturity, have vacated them.

68. Having thus explained in general the forms and structures of the cells, we shall briefly explain the operation by which the bees construct them, and by their combination form the combs.

The material of the combs is *wax*, a substance secreted beneath the ventral segments of the bodies of that class of the workers which, from this circumstance, has received the name of wax-makers. The apparatus by which the material which ultimately acquires the character of wax is secreted, consists of four pairs of membranous bags, called wax-pockets, which are situated at the base of each segment of the body, one on each side, and which in the natural condition of the body, are concealed by the segments overlapping each other. They can, however, be rendered visible by drawing out the body longitudinally, so that the part

of each segment covered by the preceding one shall be disclose (fig. 29).

In these pockets the substance to be ultimately converted into wax is secreted from the food taken into the stomach, which, transpiring from thence through the membrane of the wax-pocket, is formed there in thin laminæ. The stomach and its appendages which are endowed with these functions, though much less capacious in the nurses than in the wax-makers, is not altogether absent; and the nurses have a certain limited power of secreting wax. In them the wax-making function, however, seems to exist in little more than a rudimentary state.

Fig. 29.

69. Although the chief duty of the wax-makers is that from which they have taken their names, they are also capable of producing honey, and when the hive is abundantly furnished with combs, they accordingly change the object of their industry and produce honey instead of wax.

70. When a comb is about to be constructed, the operation is commenced by the wax-makers, who, having taken a due portion of honey or sugar, from either of which wax can be elaborated, suspend themselves one to another—the claws of the fore-legs of the lowermost being attached to those of the hind-legs of the next above them, so that they form a cluster, the external surface of which presents the appearance of a fringed curtain (fig. 30). After having remained in this state unmoved for about twenty-four hours, during which period the material of the wax is secreted, the thin laminæ into which it is formed may generally be perceived under the abdomen.

Fig. 30.

A single bee is now seen to separate itself from the cluster and to pass from among its companions to the roof of the hive, where by turning itself round, it clears a circular space for its work, about an inch in diameter. Having done this, it proceeds to lay the foundation of a comb in the following manner, if one may be permitted to apply the word foundation to the top of a suspended structure.

71. The foundress bee, as this individual is called, commences its work by seizing with one of its hind feet a plate of wax, or rather of the material out of which wax is to be constituted, from between the segments of its abdomen. The insect is

represented in this act in fig. 31. Having fixed a secure hold on the lamina, it carries it by its feet from the abdomen to its mouth, where it is taken by one of the fore-legs which holds it vertically while the tongue rolled up serves for a support, and by raising and depressing at will, causes the whole circumference to be brought successively under the action of the mandibles (fig. 32), so that the margin is soon ground into pieces. These pieces fall gradually as they are detached in the double cavity of the mandibles which are bordered with hair.

Fig. 31.

Fig. 32.

The mandibles or jaws which execute this process open in a horizontal, instead of a vertical, direction as in the case of the superior animals, and have a form resembling that of a pair of shears or scissors.

72. The fragments of the laminæ thus divided falling on either side of the mouth, and pressed together into a compact mass, issue from it in the form of a very narrow ribbon. This ribbon is then presented to the tongue by which it is impregnated with a frothy liquor, which has the same effect upon it as water has on potter's earth in the formation of porcelain paste. That this process, by which the raw material of the wax is worked and kneaded, is an extremely elaborate and artificial one, is rendered apparent by observing carefully the manœuvres of the bee's tongue in the process. Sometimes that organ assumes the form of a spatula, or apothecary's knife, sometimes it takes the form of a mason's trowel, and sometimes that of a pencil tapering to a point, never ceasing to work upon the ribbon which is being evolved from the mouth in these several forms.

After the ribbon has been thus thoroughly impregnated with moisture, and carefully kneaded, the tongue again pushes it between the mandibles, but in a contrary direction to that in which it previously passed, when the whole is worked up anew.

The substance is now converted into true wax, the characteristic properties of which it has acquired in this process. The material evolved in laminæ from the segments of the abdomen is brittle and friable, and would be as unfit for the structure of the comb as dry potter's earth would be for the formation of a vase. The liquid secreted from the mouth, with which it has been impreg-

nated, and the elaborate process of kneading which it has undergone, have totally changed its mechanical properties and have imparted to it that ductility and plasticity so eminently characteristic of wax. It has also undergone other physical changes. The laminæ taken from the abdominal segments are colourless and transparent, the substance into which they are converted being white and opaque.

73. The pieces of wax thus elaborated the insect applies against the roof of the hive, arranging them with her mandibles in the intended direction of the comb. She continues thus until she has in this way applied the wax produced from the entire laminæ, when she takes in like manner another from her abdomen, treating it in the same way. After thus heaping together all the wax which her organs have secreted, and causing it to adhere by its proper tenacity to the vaults of the hive, she withdraws from her work and is succeeded by another labourer who continues the same operations, who is followed in a like manner by a third and fourth, and so on, all disposing the produce of their labour in the direction first intended to be given to the comb.

74. Nevertheless it would seem that the curious facility by which these proceedings are directed is not altogether unerring, for it happens by chance now and then that one of the workers will commit a mistake by placing the wax in the wrong direction. In such cases, the worker which succeeds never fails to rectify the error, removing the materials which are wrongly placed, and disposing them in the proper direction.

75. The result of all these operations of the wax-makers is the construction of a rough wall of wax about half an inch long, a sixth of an inch high, and the twenty-fourth of an inch thick, which hangs vertically from the roof of the hive. In the first rough work there is no angle nor the least indication of the form of the cells. It is a mere straight and plain vertical partition of wax, roughly made, about the twenty-fourth of an inch thick, and such as can only be regarded as the foundation of a comb.

76. The duty of the *wax-makers* terminating here, they are succeeded by the *nurses*, who are the genuine artisans; standing in relation to the wax-makers in the same manner as, in the construction of a building, the masons who work up the materials into the form of the intended structure would to the common labourers. One of the nurses commences its operation by placing itself horizontally on the roof of the hive, with its head presented to the wall of wax constructed by the wax-makers. This wall or partition is intended to be converted into the system of pyramidal bases of the cells already described, and accordingly the first

labour of the nurses is directed to accomplish this change. Their first operation, therefore, is to mould on that side of the wall to which its head is directed, a pyramidal cavity having the form of the base of one of the intended cells. When it has laboured for some minutes thus, it departs and is succeeded by another, who continues the work, deepening the cavity and increasing its lateral margins by heaping up the wax on either side by means of its teeth and fore-feet, so as to give the sides a more regular form. More than twenty nurses succeed each other in this operation.

77. It must be remembered that during this process, nothing has been done on the other side of the partition, but when the cell just described has attained a certain length, other nurses approach the opposite side of the partition and commence the formation of the pyramidal base of two cells corresponding in position with that just described, and these in like manner prosecute their labours, constantly relieving each other.

78. While the nurses are thus employed in converting the rough partition into the pyramidal bases of cells, and in forming the hexagonal tubes corresponding to these pyramidal bases, the wax-makers return and, resuming their labour, increase the magnitude of the partition in every direction, the nurses meanwhile still prosecuting their operations.

After having worked the pyramidal bases of the cells of one row into their proper forms, they polish them and give them a high finish, while others are engaged in laying out the next series.

79. In fig. 33, is represented one of the faces of such a partition

Fig. 33.

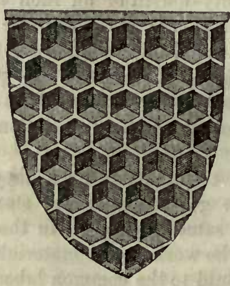
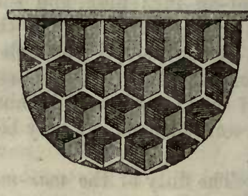


Fig. 34.



as is here described, after it has been formed into a continuous system of pyramidal bases. These are intended to represent the bases of the cells of the workers. A similar piece showing the bases of the cells of the drones is represented in fig. 34.

80. The cells themselves, consisting, as already explained, of

hexagonal prismatic tubes, are the next objects of the industry and skill of the nurses. These are cemented on the borders of the pyramidal cavities shown in figs. 26 and 27.

81. The surfaces represented in figs. 33 and 34 having a contour very unequal, the edges of the pyramidal cavities being inclined to each other, so as to form angles alternately salient and re-entrant, the first work of the bees is to form those parts of the prismatic sides of the cells which are necessary to fill up the re-entrant angles of the contours of the pyramidal bases. When this has been accomplished, the contours of all the hexagonal divisions extended over the surface of the partition, represented in figs. 33 and 34, are brought to a common level, and from that point the labour of the little artificers becomes more simple, consisting of the construction of the oblong rectangles which form the remainder of the six sides of each cell.

82. It must nevertheless be remarked, that the first row of cells, being necessarily attached to the roof of the hive, and not at its upper edge connected like the other rows with other similar cells, has an exceptional form, these being not hexagonal, but pentagonal; two of the sides of the ordinary cells being replaced by the roof of the hive, as shown in figs. 33 and 34. A corresponding exceptional form is of course also given to the bases of the first row of cells.

The combs constructed in this manner are ranged in vertical planes parallel one to the other in the hive, as shown in perspective in fig. 35, in vertical section in fig. 36, and in horizontal

Fig. 35.

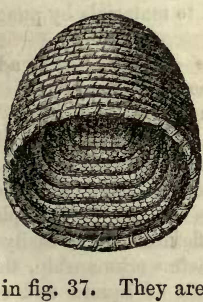
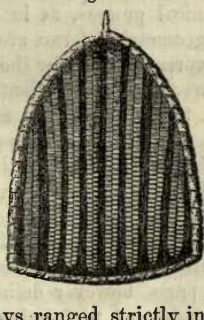


Fig. 36.



section in fig. 37. They are not always ranged strictly in single parallel lines; but are sometimes bent at an angle, as shown in fig. 37.

An end view of a comb, showing the mouths of the cells foreshadowed by perspective, is represented in fig. 38.

83. The flat sides of a comb are not strictly parallel, but

generally slightly inclined one to the other, so that the thickness gradually diminishes from top to bottom, as shown in the vertical section, fig. 36. This gradation of thickness is continued to a

Fig. 37.

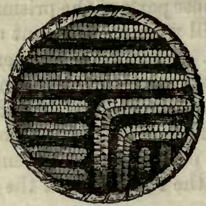


Fig. 38.

certain point, while the width of the comb is continually augmented; but so soon as the workers obtain sufficient space to lengthen it, it begins to lose this form, and the surfaces become sensibly parallel.

84. A certain class of naturalists, who have directed their attention to the history of this insect, appear to have taken a pleasure in forming hypotheses, by which it would be reduced to a mere machine. Thus, according to them, the formation of the various parts of the comb would result from a mere mechanical necessity, the organs of the insect being supposed to be so formed that the different parts of the cells would receive their forms by a mechanical process, as in certain operations in the arts the most exact geometrical forms are imparted to materials by punches and dies expressly made for the purpose.

Between such expedients and the organs of this admirable insect, there is, however, not the remotest analogy.

The mechanical instruments with which they work are the feet, the mandibles, and the tongue, the operations of which are guided by the antennæ, which are feelers of exquisite sensibility. They do not remove in their operations a single particle of wax, until the surface to be sculptured has been carefully explored by the antennæ. These organs are so flexible and so easily applied to all parts, however delicate, of their workmanship, that they are capable of performing the offices of square and compass, measuring the minutest parts with the utmost precision, so as to guide the work in the dark, and produce with unerring precision that wondrous structure called the comb.

85. It is impossible to behold a dissected comb without perceiving the geometrical necessity which connects one part with

another. In the formation of such a structure, chance can have no share. The original mass of wax is augmented by the labour of the wax-makers in the exact quantity which is necessary; and these wax-makers, who thus are constantly on the watch to observe the progress of the comb, so as to keep the artificer-bees constantly supplied with the necessary quantity of raw material, are themselves utterly destitute of the art and science necessary to construct the cells.

86. The bees never commence the construction of two contiguous and parallel combs together, for the obvious reason, as it should seem, that to make one parallel to and at a given distance from another, the actual formation of one must be first accomplished to a certain point. They therefore begin by the middle comb; and when that has been constructed to a certain depth, measured from the top of the hive, two other combs, parallel to it and at regulated distances from it at either side, are commenced; and when these again are completed to a certain depth, two others outside these are commenced, and so on. This order of proceeding is attended with a further advantage by preventing the workers on one comb from being inconveniently crowded or obtruded upon by those of the adjacent combs.

87. The labour of the bees is conducted in common, but not always simultaneously. Every partial operation is commenced by one individual bee, who is succeeded in her labours by others, each appearing to act individually in a direction depending on the condition in which she finds the work when it falls into her hands. The whole band of wax-makers, for example, is in complete inaction until one of them goes forth to lay the foundation of a comb. Immediately the labours of this one are succeeded and seconded by the others, and, when their part is done, an individual nurse-bee goes to lay out the plan of the first cell, and is in like manner succeeded continuously by others.

88. "The diameter of the cells intended for the larvæ of the workers is alway $2\frac{2}{5}$ lines, and that of those meant for the larvæ of the males or drones $3\frac{1}{3}$ lines. The male-cells are generally in the middle of the combs, or in their sides; rarely in their upper part. They are never insulated, but form a corresponding group on both sides the comb. When the bees form male-cells below those of neuters, they construct many rows of *intermediate* ones, the diameter of which augments progressively till it attains that of a male-cell; and they observe the same method when they revert from the male-cells to those of workers. It appears to be the disposition of the *queen* which decides the kind of cells that are to be made; while she lays the eggs of workers, no male-cells are constructed; but when she is about to

lay the eggs of males, the workers appear to know it, and act accordingly. When there is a very large harvest of honey, the bees increase the diameter and even the length of their cells. At this time many irregular combs may be seen with cells of twelve, fifteen, and even eighteen lines in length. Sometimes, also, they have occasion to shorten the cells. When they wish to lengthen an old comb, the sides of which have acquired their full dimensions, they gradually diminish the thickness of its edges, gnawing down the sides of the cells till it assumes the lenticular form; they then engraft a mass of wax round it, and so proceed with new cells." *

89. The number of cells contained in the combs of a well-stocked hive is considerable. In a hive twenty inches high and fourteen inches diameter, they often amount to forty or fifty thousand. A piece of comb, measuring fourteen inches long and seven inches wide, containing about 4000 cells, is frequently constructed in twenty-four hours.

90. Nothing can be more admirable than the tender solicitude and foresight shown by the bee towards its offspring. Although these insects provide a great number of cells, as storehouses, for the honey intended for the use of the community, yet the object which more exclusively engrosses them is the care of their young, to the provision and rearing of which they sacrifice all personal and selfish considerations. In a new swarm, accordingly, the first care of these insects is to construct cradles for their young, and the next, to provide an ample store of a peculiar sort of *pap*, called *bee-bread*, for their food.

This bee-bread consists of the pollen of flowers, which the workers at this time are incessantly employed in gathering, flying from flower to flower, brushing from the stamens their yellow treasure, which they collect in the little baskets with which their hind-legs are so admirably provided. They then hasten back to the hive, where, having deposited the store thus collected, they return to seek a new load.

Another troop of labourers are in constant attendance in the hive to receive the stock of bee-bread thus collected, which they carefully store up until such time as the queen has laid her eggs. These eggs she places in an upright position in the bottoms of the cells, where they are severally hatched.

91. The bee-bread is converted into a sort of pap, or whitish jelly, by being swallowed by the bee, in the stomach of which it is probably mixed with honey and then regurgitated.

The moment the young brood issue from the eggs in the state of larvæ, they are diligently fed with this jelly by the class of bees

* Kirby, i. 419.

called nurses, who attend them with all the solicitude implied by their title, renewing the pap several times a day, as fast as it is consumed.

The curious observer will see, from time to time, different nurses introduce their heads into the cells containing the young. If they see that the stock of pap is not exhausted, they immediately withdraw and pass on to other cells; but if they find, on the contrary, the provision consumed, they never fail to deposit a fresh supply. These nurses go their rounds all day long in rapid succession thus surveying the cradles, and never stopping except where they find the supply of food nearly exhausted.

92. That the duty of these tender nurses is one which requires the exertion of some skill will be understood, when it is stated that the quality of food suitable to the young varies with their age. When they first emerge from the egg the jelly must be thin and insipid, and, according as they approach to maturity, it requires to be more strongly impregnated with the saccharine and acid principles.

Not only does the food of the larva thus require to be varied according to its age, but the food to be supplied to different larvæ is altogether different. The jelly destined for the larvæ which are to become queens, is totally different from that prepared for those of drones and workers, being easily distinguished by its sharp and pungent flavour; and it is probable, also, that the jelly appropriated to the drones differs from that upon which the workers are reared.

These insects, moreover, exhibit as much economy as skill; the quantity of food provided being as accurately proportioned to the wants of the young as its quality is to their varying functions. So accurately is the supply proportioned to the wants of the larvæ, that, when they have attained their full growth and are about to undergo their final metamorphosis into nymphs, not an atom of bee-bread is left unconsumed.

93. At the epoch of this metamorphosis, when the nymph needs seclusion to spin its cocoon, and has no further occasion for food, these tender nurses, with admirable foresight, terminate their cares by sealing up each cell, enclosing the nymph with a woven lid.

In all the maternal cares described above, neither the drones nor the queen participate. These duties fall exclusively upon the workers, and are divided between them, as has been explained, the task of collecting the bee-bread being appropriated to one set, and that of feeding and tending the young to another. This duty has no cessation; as the queen lays her eggs successively and constantly, the young arrive successively at the epoch of their first metamorphosis; and, consequently, so soon as some are sealed up and

abandoned by the nurses to spin their cocoons, others issue from the egg and demand the same maternal care; so that these nurses spend their whole existence in the discharge of the offices here described.

94. Although the organisation of other species of the bee does not approach to the perfection of the hive-bee here described, it is nevertheless worthy of attention and study.

The humble-bees, which so far as respects their social policy, compared with the hive-bee, may be regarded as rude and uncivilised rustics, exhibit nevertheless marks of affection for their young quite as strong as their more polished neighbours.

Unlike the queen of the hive, the females take a considerable share in the education of the young. When one of these provident mothers has constructed with great labour and much skill a commodious woven cell, she furnishes it with a store of pollen moistened with honey, and, having deposited six or seven eggs in it, carefully closes the opening and all the interstices with wax; but her maternal cares do not end here. By a strange instinct, probably necessary to restrain an undue increase of the population, the workers, while she is laying her eggs, endeavour to seize them, and, if they succeed, greedily devour them. Her utmost vigilance and activity are scarcely sufficient to save them; and it is only after she has again and again repelled the murderous intruders, and pursued them to the furthest verge of the nest, that she succeeds in accomplishing her object; and even when she has sealed up the cell containing them, she is obliged to continue to guard it for six or eight hours; since otherwise the gluttonous workers would break it open and devour the eggs. The mother is conscious, however, by a heaven-inspired knowledge, of the time when the eggs will cease to excite the appetites of the depredators.

After this the cells remain unmolested until the larva issues from the eggs. The maternal cares having there ceased, the workers, before so eager to devour the eggs, now assume the character of nurses. They know the precise hour when the larvæ will have consumed the stock of food, provided for them by maternal care, and from that time to the period of their maturity these nurses continually feed them with honey or pollen, introduced in their proboscis through a small hole in the cover of the cell opened for the purpose, and then carefully closed.

95. These nursing-workers also perform another duty of a most curious and interesting description. As the larva increases in size, the cell, which has been appropriated to it, becomes too small for its body, and in its exertions to obtain room it splits the thin woven walls which confine it. The workers, who are constantly on the watch for this, lose no time in repairing the breach, which

they patch up with wax as often as the fracture takes place, so that in this way the cell increases in size until the larva arrives at maturity.

96. As in the case of the hive-bee already described, the larva after the first metamorphosis, is shut up in the enlarged cell to spin its cocoon. When this labour has been completed, and that the perfect insect is about to issue, the workers still discharging the duty of tender foster-parents, set about to assist the little prisoner in cutting open the cocoon, from which it emerges in its perfect state.

97. While in the pupa state, however, another tender and considerate measure of the workers must not be passed without notice. It is essential to the well-being of the pupa that while concealed in the cocoon it should be maintained at a genial temperature. To secure this object, the workers collect upon the cocoons in cold weather and at night, so that by brooding over them they may impart the necessary warmth.

98. The following curious anecdote connected with this subject is related by Huber.

"He put under a bell-glass about a dozen humble-bees, without any store of wax, along with a comb of about ten silken cocoons, so unequal in height that it was impossible the mass should stand firmly. Its unsteadiness disquieted the humble-bees extremely. Their affection for their young led them to mount upon the cocoons for the sake of imparting warmth to the enclosed little ones, but in attempting this the comb tottered so violently that the scheme was almost impracticable. To remedy this inconvenience, and to make the comb steady, they had recourse to a most ingenious expedient. Two or three bees got upon the comb, stretched themselves over its edge, and with their heads downwards fixed their fore-feet on the table upon which it stood, whilst with their hind-feet they kept it from falling. In this constrained and painful posture, fresh bees relieving their comrades when weary, did these affectionate little insects support the comb for nearly three days. At the end of this period they had prepared a sufficiency of wax, with which they built pillars that kept it in a firm position: but by some accident afterwards, these got displaced, when they had again recourse to their former manœuvre for supplying their place; and this operation they perseveringly continued, until M. Huber, pitying their hard task, relieved them by fixing the object of their attention firmly on the table." *

It is impossible not to be struck with the reflection, that this most singular fact is inexplicable on the supposition, that insects are impelled to their operations by a blind instinct alone. How

* Linnæan Trans., vi. 247, *et seq.*

could mere machines have thus provided for a case which in a state of nature has probably never occurred to ten nests of humble-bees since the creation? If in this instance these little animals were not guided by a process of reasoning, what is the distinction between reason and instinct? How could the most profound architect have better adapted the means to the end—how more dexterously *shored* up a tottering edifice, until his beams and his props were in readiness? *

99. The following remarkable example of the care bestowed by the nurses in keeping the pupa warm, more especially during the day which immediately precedes its exit from the cocoon as a perfect insect—an epoch, when as it would seem it is more especially necessary that it should be maintained at an elevated temperature,—was supplied by Mr. Newport. That naturalist observed that in the process of incubation, the humble-bee at that particular stage increased considerably the force of its respiration. To render the purpose of this intelligible to the reader not accustomed to physiological enquiries, it may be necessary to state that in the act of respiration the oxygen, which is one of the constituents of the atmosphere, enters into combination with the carbon and hydrogen, which compose part of the body of the animal. Now this combination being identical with that which produces heat in a common coal fire or the flame of a lamp, the same effect is produced in the animal economy from the same cause; and hence it arises that the development of heat in the body is always so much the greater, in proportion to the increased activity of respiration.

100. To return to the hive-bee, it was observed by Mr. Newport that in the early stage of the incubation of the pupa, the rate of respiration of the insect is very gradual, but becomes more and more frequent as the epoch approaches at which it issues from the cocoon; the number of respirations per minute then amounting to 120 or 130.

Mr. Newport states that he has seen a bee upon the combs continue perseveringly to respire at that rate for eight or ten hours, until its temperature was greatly increased and its body bathed in perspiration. When exhausted in this way it would retire from its maternal duty and give place to another foster-mother, who would proceed in the same way to impart warmth to the pupa.

In one case Mr. Newport found that while the thermometer in the external air stood at 70·2, it rose on the lips of these cells which were not brooded upon at the moment, to 80·2, but when placed in contact with the bodies of the brooding bees, it rose

* Kirby, Int., i. 320.

to 92·5. It appears therefore that by the voluntary increase of their respiration they were enabled to impart to the nymph enclosed in the cocoon 12·3 additional degrees of heat.*

101. In every well-filled hive the combs are ranged in parallel planes, as shown in figs. 36, 37; and that no space may be lost, while at the same time sufficient room is left for the movements of the workers, the open spaces between the parallel combs leave a width just sufficient to allow two bees easily to pass each other. These open spaces are the streets of the apiarian city, the highways along which the building materials are carried while the combs are in process of construction, through which the supply of provisions is carried to the stores, and food to the young, who are being reared in the cells.

But since the nurses must tend the cells of all the combs, and therefore pass successively and frequently from street to street, they would be compelled to descend to the lower edge of the comb to arrive at an adjacent street, unless cross alleys were provided at convenient points to abridge such journeys. The prudent architects foresee this in laying out their city, and make such passages, alleys, or arcades, by which the bees can pass from any street to the adjacent parallel street, without going the long way round.

102. On the return of spring, when the genial temperature of the weather begins to produce its wonted effects on vegetation, and when the vernal plants which the bees love begin to put forth their foliage and flower, the busy population of the hive recommence their labours; and the queen, who has passed the winter in repose, attended by her devoted subjects, and feeding on the stores laid up by them during the previous season, commences laying her great brood of eggs. At this epoch she is much larger than at the cessation of her laying in the autumn. Before she deposits an egg, she examines carefully the cell destined for it, putting her head and shoulders into it, and remaining there for some time, as if to assure herself that the cradle of her offspring has been put in proper order. Having satisfied herself of this, she withdraws her head, and introducing the posterior extremity of her abdomen deposits a single egg upon the pyramidal base of the cell, which adheres there in the manner already described.

She then passes to another empty cell, where, after the same precautions, she deposits another egg, and so continues, sometimes committing to the cells two hundred eggs and upwards in the day.

103. In this operation, so essential to the maintenance of the population, she is assiduously followed and most respectfully

* Philosophical Trans., 1837, p. 296.

surrounded by a certain train of her subjects, appointed apparently to attend her, and form the ladies-in-waiting on the occasion. They range themselves in a circle around her (fig. 39). From time to time

Fig. 39.—The queen depositing her eggs in the cells, surrounded by her suite.

the individuals of her suite approach her and present her with honey. They enter the cells where the eggs have been deposited, and carefully clean them, and prepare them for the reception of the pap which is to feed the young when it issues from the egg.

104. In some exceptional cases, where her majesty is rendered over prolific by any accidental cause, the eggs will drop from her faster than she can pass from cell to cell, and in such cases two or more eggs will be deposited in the same cell. Since the cells are constructed only of sufficient magnitude for the due accommodation of a single bee, the royal attendants in such cases always take away the supernumerary eggs, which they devour, leaving no more than one in each cell (fig. 40).

The eggs are oval and oblong, about the twelfth of an inch in length, of a bluish white colour, and a little bent. They are hatched by the natural warmth of the hive (from 76° to 96° Fahr.), in from three to six days, the interval depending on the temperature of the weather.

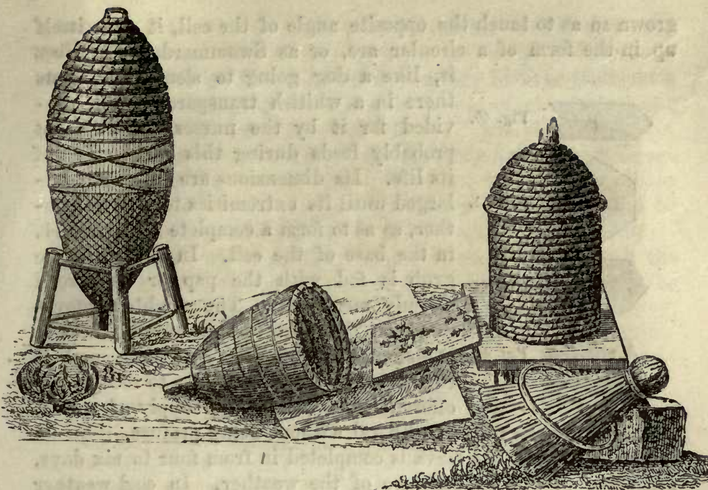


Fig. 58.—VILLAGE HIVES.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER IV.

105. The larvæ.—106. Transformation of worker nymph.—107. Worker cells.—108. Treatment of a young worker.—109. Of the drone.—110. Drone nymph.—111. Royal cell and nymph.—112. Its treatment.—113. Honey cells.—114. Pasturage—progress of work.—115. Construction of comb.—116. Remarkable organisation.—117. Magnitude and weight of bees.—118. Character of queen.—119. Royal jealousy.—120. Principle of primogeniture.—121. Assassination of rivals.—122. Battle of virgin queens.—123. Reason of mutual hostility.—124. Result of the battles.—125. Battle of married queens.—126. Battle of a virgin with a fertile queen.—127. Sentinels at the gates. Treatment of an intruding queen.—128. Remarkable proceeding of bees that have lost their queen—effect of her restoration.—129. Effect of the introduction of a new queen.—130. Policy of the hive.—131. Operations at the beginning of a season.

105. THE larva which issues from the egg is a white grub, destitute of legs, having its body divided transversely by a series of parallel circular grooves into annular segments. When it has

grown so as to touch the opposite angle of the cell, it coils itself up in the form of a circular arc, or as Swammerdam describes it, like a dog going to sleep. It floats there in a whitish transparent fluid, provided for it by the nurses, on which it probably feeds during this early stage of its life. Its dimensions are gradually enlarged until its extremities touch one another, so as to form a complete ring, fig. 41, in the base of the cell. In this state the grub is fed with the pap or bee bread already mentioned. The slightest movement on the part of the nursing bees is sufficient to attract its attention, and it eagerly opens its little jaws to receive the offered nourishment, the supply of which, presented by the nurse, is liberal without being profuse.


Fig. 40.


Fig. 41.


Fig. 42.


Fig. 43.

The growth of the larva is completed in from four to six days, according to the temperature of the weather. In cool weather the development takes two days more than in warm weather.

When it has attained its full growth, it occupies the whole breadth and a great part of the length of the cell. The nurses at this time knowing that the moment has arrived at which the first metamorphosis, in which the grub is changed into a nymph, takes place, discontinue the supply of food, and close up the mouth of the cell by a light brown waxen cover, which is convex externally. This convexity of the cover is greater in the drone cells than in those of the workers. The covers of the honey cells are, on the contrary, made paler in colour, and quite flat or even a little concave externally.

Fig. 44.

When the larva has been thus enclosed, it immediately commences, like the silk-worm, to spin a cocoon. In this labour it is incessantly employed, lining the sides of its cell and encasing its own body in a white silken robe. The threads which form this mantle issue from the middle of the under lip of the nymph, as the insect in this intermediate state between that of the grub and the perfect bee is called. This thread consists of two filaments, which, issuing from two adjoining orifices in the spinner, are then gummed together.

106. The nymph of a worker spins its robe in thirty-six hours, and after passing three days in this preparatory state, it undergoes so great a change as to lose every vestige of its previous form. It

is clothed with a harder coating, with dark brown scales, fringed with light hairs. Six annular segments are distinguished on its abdomen, which are inserted one into another like the joints of a telescope tube, and give the insect the power of elongating and contracting itself within certain limits. The breast is also invested with a sort of brush of grey feathery hairs, which as age advances assume a reddish hue. In about twelve days all the parts of the body of the perfect insect are developed, and can be seen through the semi-transparent robe in which it is clothed.

About the twenty-first day, counting from that on which the egg was laid, the second metamorphosis is complete, and the perfect insect, gnawing through the cover of its cell, issues into life, leaving behind it the silken robe which it wore in the intermediate state of nymph. This is closely attached to the inner surface of the cell in which it was woven, and forms a permanent lining of it. By this cause the breeding cells become smaller and smaller, as the eggs are successively hatched in them, until at length their capacity becomes too limited for the full development of the nymphs. They are then turned into store rooms for honey.

Fig. 45.

Pupa of a worker.

107. In fig. 46 is represented a piece of comb, consisting exclusively of workers' cells, in different states. Several, *c*, *c*, *c*, &c., are closed, the nymph not having yet undergone its final metamorphosis. A bee having arrived at the perfect state and gnawed open the

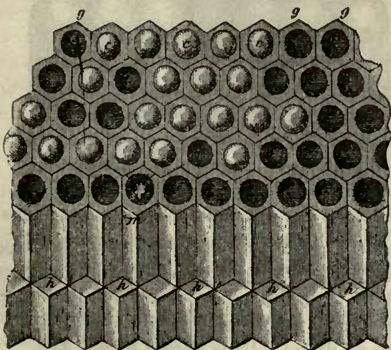


Fig. 46.

cover of its cell, is shown at *m*. The cells, *h*, *h*, have their openings on the opposite side of the comb, and *g*, *g*, *g*, are cells from which the perfect insects have already issued.

108. When a young bee, after its final metamorphosis, has issued from the cell, the nurses crowd round it, carefully brushing it, giving it nourishment and showing it the way through the hive. Others meanwhile are occupied in cleaning the cell from which it has issued and putting it in order to receive another egg if it be still large enough, and if not, to receive a store of honey.

The young bee is not sufficiently strong to fly on the first day. It is only on the morrow, after being well fed and brushed down by the nurses, and having taken a walk from time to time through the combs, that it ventures on the wing.

109. The drone passes three days in the egg, and continues to receive the care of the nurses as a grub until the tenth day, when it passes into the state of nymph, and is sealed up in its cell by the

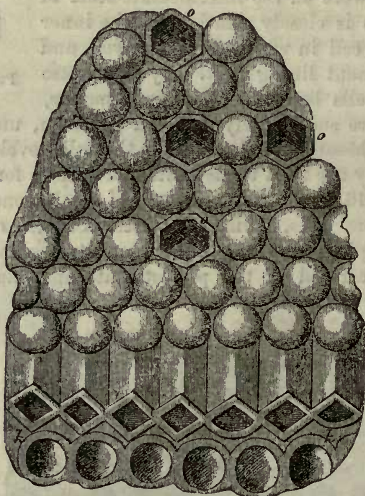


Fig. 47.

nurses with a very convex cover. As already stated, the drone grub being larger than that of the worker, the cell assigned to it is proportionately more capacious, and the cover by which as a nymph it is shut up is much more convex externally. A piece of comb consisting of drone cells is shown in fig. 47.

Some cells, *o*, *o*, *o*, being those from which the perfect insect has issued, are open and empty.

Near the borders of the comb, where local circumstances render it necessary to modify the principles of its architecture so as to accommodate the cells to their position in the hive, may be

observed several, *k*, *k*, of unusual and irregular forms. While some such cells have six unequal sides, others have only four or five. It seems also that in the case of certain cells intended only for the reception of honey, the bee is not at all as scrupulous in the observance of architectural regularity as in the case of brood cells.

110. The drone nymph undergoes its final metamorphosis and becomes a perfect insect, from the twenty-fifth to the twenty-seventh day from that on which the egg is laid, according to the temperature of the hive. It is therefore six or seven days later in arriving at maturity than the worker.

111. The changes to which the young of the royal family are subject before arriving at maturity, are different from those above stated. It has been already explained that the royal cells are vertical instead of being horizontal, are egg-shaped instead of being hexagonal, and in fine are much more capacious than those

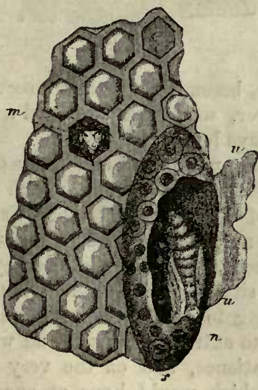


Fig. 48.

of the drones or workers. One of these cells is shown at *r s* in fig. 48, a part, *u u*, being removed to show the royal nymph within it. It will be observed that a much larger space is given to the royal nymph than is allowed either to that of the worker or the drone, the bodies of which nearly fill their respective cells. The royal nymph is always placed, as shown in the figure, with her head downwards.

The progressive formation of a royal cell is shown in fig. 49. It is unfinished, as at *a*, when the egg is deposited; and is gradually enlarged, *c*, as the grub increases in size; and is sealed up, *b*, when it is transformed into a nymph.

The grub issues from the egg on the third day, becomes a nymph from the eighth to the eleventh day, and undergoes its

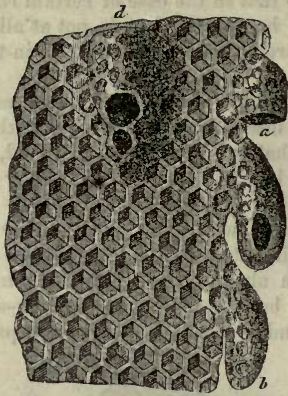


Fig. 49.

final metamorphosis, becoming a perfect insect on the seventeenth day. It is, however, sometimes detained a prisoner in the cell for seven or eight days longer.

112. Naturalists are not agreed as to some of the circumstances attending the treatment of the young, which we have here given on the authority of Feburier and other French entomologists. Mr. Dunbar, in reference to the circumstances attending the first issuing of the perfect insect from the cell, says that in hundreds of instances their situation has excited his compassion, when after long struggling to escape from its cradle, it has at last succeeded so far as to extrude its head, and when labouring with the most eager impatience, and on the very point of extricating its shoulders also, which would have at once secured its exit, a dozen or two of workers, in following their avocations, have trampled without ceremony over the struggling creature, which was then forced for the safety of its head, quickly to pop down again into the cell and wait until the unfeeling crowd had passed, before it could renew its efforts. Again and again will the same impatient efforts be repeated by the same individual, and with the same mortifying interruptions, before it succeeds in obtaining its freedom. Not the slightest attention or sympathy on the part of the workers in these cases was ever observed by Mr. Dunbar, nor did he ever witness the parental cares and sage instruction given to the young which are described by the French entomologists.

Positive, however, is more entitled to consideration than negative testimony, and it cannot be doubted that Feburier and others witnessed those cares, guidance, and education which they have so well described. Besides, Dr. Bevan admits that he has seen assistance rendered to the infant drones. So soon as the young insect has been cleaned of its exuviæ and regaled with honey by the nurses, the latter clean out the cell exactly as we have already described.

113. A piece of comb is shown in fig. 50, the upper part A, of which contains honey-cells closed with flat sides of wax. The cells, *c c*, &c., contain pollen, and *c′ c′*, &c., propolis. The cells

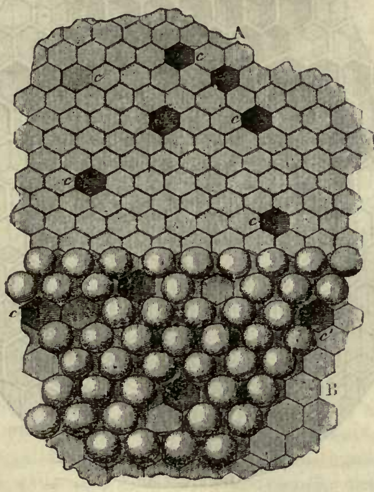


Fig. 50.

of the upper part are those which originally belonged to workers, and those of the lower part, with convex covers, are occupied by the drone nymphs.

114. The various flowers and herbs which supply the materials for honey, wax, and propolis taken collectively, are called the pasturage of the bees, and it is observed that when this pasturage is very abundant, the bees, eager to profit by the rich harvest, depart from their habit of conveying their booty first to the uppermost cells of the comb, so as to fill them gradually downwards. On the contrary, upon arriving with their load, and eager to return for a fresh supply, they unload themselves in the nearest empty cells they can find. The wax-makers meanwhile charge

themselves with the labour of taking the provisions thus deposited from the lower to the upper parts of the combs.

115. In fig. 51, is shown a piece of comb in process of construction. It has, as usual, an oval form. The wax, of which it is formed, is white, but as it advances in age it takes successively a

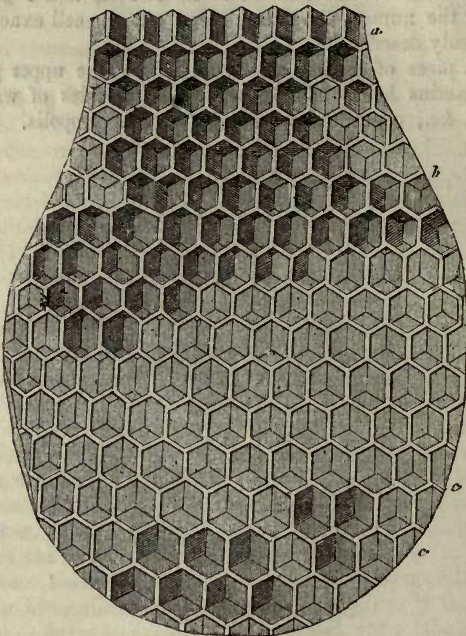


Fig. 51.

darker and darker colour, being first yellow, then reddish, and sometimes even becomes blackish. The sides of the cells are gradually thickened, by the constant adhesion and accumulation of the cocoons, of which the nymphs successively bred in them are divested. The top and sides of the comb are every where strongly cemented, by a mixture of propolis and wax, to the roof and sides of the hive. These structures are almost never known to fall except by some accidental cause external to the hive, such as a blow or the too intense heat of the sun dissolving the cement.

116. The character and manners of the bee have an intimate relation with its social organisation. We have seen that in the

building of their city this organisation is never for a moment lost sight of. The chambers vary in number, magnitude, form, and position. Those designed for the members of the royal family are few and exceptional, those for the drones much more numerous, but about one hundred times less numerous than those of the workers. The magnitudes are in like manner strictly regulated, in relation to the volume of the body of the occupant, except the royal chambers to which a magnitude is given much greater in proportion than that of the bodies of the royal tenants. The object to be attained by this increased capacity, as well as by the vertical position specially given to the royal cells, has not been ascertained.

117. How little relation there exists between mere bodily magnitude, and the faculties which govern acts so remarkable as those of the insects now before us, will be understood when it is stated that, according to the experiments of Reaumur, the average weight of the bee is such that 336 go to an ounce, and 5376 to a pound; and John Hinton found that 2160 workers would not more than fill a common pint.

118. Having thus explained in a general way the persons composing the society, and the structure and architecture of their dwellings, we shall proceed to notice some of the more remarkable traits of their character and manners.

It has been already explained that the community of the hive bees is strictly a female monarchy. The jealous Semiramis of the hive, as Kirby observes, will have no rival near her throne. It may, therefore, be asked to what purpose are the sixteen or twenty princesses reared, for whom royal chambers are provided, and who are treated in all respects by the nurses as aspirants to the throne? This will be comprehended, however, when it is remembered that the hive, soon after the commencement of the season, becomes so enormously over-peopled, that emigration becomes indispensable, and that with each emigrant swarm a queen is necessary. Either therefore the queen regnant must go forth, abdicating the throne, in which case it is ascended by the eldest of the princesses, or the latter is raised to the sovereignty of the emigrating colony. Now, since a rapid succession of swarms issue from the hive, especially in the early part of the season, sometimes as many as four in eighteen days, and since one queen is required for each, a proportionately numerous royal family is required to fill so many independent thrones.

119. When the growth of several princesses and their arrival at maturity occurs, before the increase of the population renders emigration necessary, so as to create thrones for them, the most violent jealousy is excited in the breast of the queen regnant, who is either mother or sister to these several queens presumptive,

and her royal breast is fired with agitation, nor does she rest until she has engaged in mortal conflict with her rivals, and either puts them to death or suffers death at their hands.

120. When a hive, having lost its queen by emigration or otherwise, is provided with several royal cells, which generally happens, the first princess which issues from these in the perfect state immediately ascends the throne in right of primogeniture. Although her rivals are not yet in a condition to dispute the title, they, nevertheless, excite her jealousy in the highest degree. Scarcely ten minutes elapse from the moment she has attained the perfect state, and issued from the royal cell, when she goes in quest of the other royal cells, assails with fury the first she encounters, and having gnawed a large hole in it she introduces the posterior extremity of her abdomen, and kills her rival with her sting.

121. A crowd of workers, who are passive spectators of this, approach the cell, and enlarging the breach, drag out the corpse of the murdered princess, who, in such cases, has already assumed the perfect state. If the queen attack in like manner a cell of which the occupant is still in the state of nymph, she does not waste her strength in slaying it, well knowing that its premature exposure will do the work of death. The workers, in this case also enlarging the breach made by the queen, pull out the nymph, who immediately perishes.

122. Huber, who witnessed, and has described all these curious proceedings, being desirous to ascertain what would happen if two rival queens, both in the perfect state, found themselves together in the same hive, produced artificially that contingency on the 15th May, 1790. He managed to provide in the same hive royal cells, in an equal stage of forwardness, so that virgin queens issued from two of them almost at the same moment.

When they appeared in presence of each other they fell upon each other with all the appearance of insatiable fury, and so engaged one with the other, that each held in her mandibles the antennæ of the other. They were engaged breast to breast, and abdomen to abdomen, so that if each had put forth her sting, mutual death would have been the consequence. But as if nature had forbidden this mutual destruction, the combatants disengaged themselves from each other's grasp, and fled one from the other with the greatest precipitation.

Huber says that this was not a mere incident which might have occurred in a single case, but would not occur in others, for he repeated the same experiment frequently, and it was always followed by the same result. It seemed, therefore, as though it were a case foreseen by nature, and that one only of the combatants should fall in such combats.

123. Nature has ordained that in each hive there shall be one, and but one queen, and when by any concurrence of circumstances a second appears, one or the other is doomed to destruction. But it is not permitted to the common class of the people to do execution on a royal personage, since in that case it might not be possible to secure unanimity as to the particular queen who is to be preserved, so that different assemblages of the people might at the same time assail different queens, and so leave the hive without a sovereign. It was, therefore, necessary, as Huber argues, that the extermination of the superfluous queens should be left to the queens themselves, and that they should in their combats be filled with an instinctive horror of mutual destruction.

Some minutes after the two queens above mentioned had separated and retired from each other, and when their fears had time to subside, they again prepared to approach each other. They engaged once more in the same position, involving the danger of mutual destruction, and as before, once again separated and mutually fled each other.

124. During all this time the greatest agitation prevailed among the population who assisted at the scene, more especially when the two combatants separated. On two different occasions the workers interfered to prevent them from flying from one another. They arrested them in their flight, seizing them by the legs and detaining them prisoners for more than a minute. In fine, in a last attack, one of the queens, more active and furious than the other, taking her rival unawares, laid hold of her with her mandibles at the insertion of the wing, and then mounting on her back, and bringing the posterior extremity of her abdomen to the junction of one of the abdominal segments of her adversary, stabbed her mortally with her sting. She then let go the wing which she had previously held and withdrew her sting.

The vanquished queen fell, dragged her body slowly along for a certain distance, and soon after expired.

125. Having thus ascertained the conduct of virgin queens under the circumstances here described, Huber made arrangements for observing the conduct of queens who were in a condition to produce eggs. For this purpose he placed a piece of comb on which three royal cells had been constructed in a hive with a laying queen. The moment they caught her eye she fell upon them, opened them at their bases, and surrendered them to the attendant workers, who lost no time in dragging out the royal nymphs, greedily devouring the store of food which remained in the cells, and sucking whatever was in the carcases. Having accomplished this they proceeded to demolish the cells.

It was now resolved to ascertain what would be the behaviour of

a queen-mother regnant in case a stranger queen pregnant were introduced into the hive. A mark having been previously made upon the back of such a queen, so that she might be afterwards identified, she was placed in the hive. Immediately on her appearance the workers collected in a crowd around her, and formed as usual a circle of which she was the centre, the heads of all the remaining crowd being directed towards her. This very soon became so dense that she became an absolute prisoner within it.

While this was going on, a similar ring was formed by another group of workers round the queen regnant, so that she was likewise for the moment a prisoner.

The two queens being thus in view of each other, if either evinced a disposition to approach and attack the other, the two rings were immediately opened, so as to give a free passage to the combatants; but the moment they showed a disposition to fly from each other, the rings were again closed, so as to retain them in the spot they occupied.

At length the queen regnant resolved on the conflict, and the surrounding crowd, seeming to be conscious of her decision, immediately cleared a passage for her to the place where the stranger stood perched on the comb. She threw herself with fury on the latter, seized her by the root of the wing, and fixed her against the comb so as to deprive her of all power of movement or resistance, and then bending her abdomen inflicted a mortal stab with her sting, and put an end to the intruder.

Fig. 52.

126. A fruitful queen full of eggs was next placed upon one of the combs of a hive over which a virgin queen already reigned. She immediately began to drop her eggs, but not in the cells; nor did the workers, by a circle of whom she was closely surrounded, take charge of them; but, since no trace of them could be discovered, it is probable that they were devoured.

The group, by which this intruding queen was surrounded, having opened a way for her, she moved towards the edge of the comb, where she found herself close to the place occupied by the legitimate virgin queen. The moment they perceived each other, they rushed together with ungovernable fury. The virgin, mounting on the back of the intruder, stabbed her several times in the abdomen, but failed to penetrate the scaly covering of the segments. The combatants then, exhausted for the moment, disengaged themselves and retired. After an interval of some

minutes they returned to the charge, and this time the intruder succeeded in mounting on the back of the virgin and giving her several stabs with her sting, which, however, failed to penetrate the flesh. The virgin queen, succeeding in disengaging herself, again retired. Another round succeeded, with the like results, the virgin still coming undermost, and, after disengaging herself, again retiring. The combat appeared for some time doubtful, the rival queens being so nearly equal in strength and power, when at last, by a lucky chance, the virgin sovereign inflicted a mortal wound upon the intruder, who fell dead on the spot.

In this case, the sting of the virgin was buried so deep in the flesh of her opponent, that she found it impossible to withdraw it, and any attempt to do so by direct force would have been fatal to her. After many fruitless efforts she at length adopted the following ingenious expedient with complete success. Instead of exerting her force on the sting by a direct pull, she turned herself round, giving herself a rotatory motion on the extremity of her abdomen where the sting had its insertion, as a pivot. In this way she gradually *unscrewed* the sting.

127. The gates of the hive are as constantly and regularly guarded night and day as those of any fortress. The workers charged with this duty are, of course, regularly relieved. They scrupulously examine every one who desires to enter; and, as though distrustful of their eyes, they touch all visitors with their antennæ. If a queen happens to present herself among such visitors, she is instantly seized and prevented from entering. The sentinels grasp her legs or wings with their mandibles, and so surround her that she cannot move. As the report of the event spreads through the interior of the hive, large reinforcements of the guard arrive, who augment the dense ranks which hold the strange queen in durance.

In general, in such cases, the intruding queen is thus detained prisoner until she dies from want of food. It is remarked that the guard, who thus surround and detain her, never use their stings upon her. In one instance Huber attempted to extricate a queen, thus surrounded, by taking her directly out of the ring of guards. This excited the rage of the guard to such a pitch that, putting forth their stings, they rushed blindly not only on the queen but on each other. The queen, as well as several of the guard, were killed in the mêlée.

128. When the sovereign of the hive is removed or accidentally destroyed, the population seem at first to be wholly unconscious of their loss, and pursue their usual avocations as if nothing had happened. But after the lapse of some hours they begin to manifest a certain degree of uneasiness. This gradually increases,

until the entire hive becomes a scene of tumult. The wax-makers abandon their work, the nurses desert the infant brood; they run here and there in all directions through the streets and passages of the hive as if in delirium. That all this disorder and alarm is produced by the report spreading that the sovereign has disappeared, was proved to demonstration by Huber, who restored to the hive the queen he had purposely withdrawn. Her majesty was instantly recognised by those who happened to be assembled at the place of her restoration; but what is remarkable is that the intelligence of her return was immediately spread through every part of the hive, so that the bees in its most remote streets and alleys, who had no opportunity of personally seeing her majesty, were informed of her re-appearance, as was proved by the restoration of order and tranquillity, and the resumption of their usual labours by all classes of the population.

129. If, instead of restoring to the hive the queen herself, a new queen, stranger to the population, be introduced, she will not at first be accepted. She will, on the contrary, be guarded and imprisoned by a ring of bees, in the same manner as a strange queen is treated in a hive which still retains its reigning sovereign. But if she survives sixteen or eighteen hours in this confinement, the guard around her gradually disperses itself, and the lady enters the hive and assumes without further question the state and dignity of queen, and becomes the object of the homage paid to the sovereign.

As we have already stated, the first work which the population undertakes, after being assured of the loss of its queen, is directed to obtain a successor to her. If there be not royal cells prepared, they set about their construction. While this work was in progress, and in twenty-four hours after their queen had been taken from them, Huber introduced into the hive a fruitful queen in the prime of life, being eleven months old. Not less than twelve royal cells had been already commenced and were in a forward state. The moment the strange queen was placed on one of the combs, one of the most curious scenes commenced which was probably ever witnessed in the animal world, and which has been described by Huber.

The bees who happened to be near the stranger approached her, touched her with their antennæ, passed their probosces over all parts of her body, and presented her with honey. Then they retired, giving place to others, who approached in their turn and went through the same ceremony. All the bees who proceeded thus clapped their wings in retiring and ranged themselves in a circle round her, each, as it completed the ceremony, taking a position behind those who had previously offered their respects. A

general agitation was soon spread on those sides of the combs corresponding with that of the scene here described. From all quarters the bees crowded to the spot, and each group of fresh arrivals broke their way through the circle, approached the new aspirant to the throne, touched her with their antennæ and probosces, offered her honey, and, in fine, took their rank outside the circle previously formed. The bees forming this sort of court circle clapped their wings from time to time, and fluttered apparently with self-gratification, but without the least sign of disorder or tumult.

At the end of fifteen or twenty minutes from the commencement of these proceedings the queen, who had hitherto remained stationary, began to move. Far from opposing her progress or hemming her in, as in the cases formerly described, the bees opened the circle on the side to which she directed her steps, followed her, and, ranging themselves on either side of her path, lined the road in the same manner as is done by military bodies in state processions. She soon began to lay drone eggs, for which she sought and found the proper cells in the combs which had been already constructed.

While these things were passing on the side of the comb where the new queen had been placed, all remained perfectly tranquil on the opposite side. It seemed as though the bees on that side were profoundly ignorant of the arrival of a new queen on the opposite side. They continued to work assiduously at the royal cells, the construction of which had been commenced on that side of the comb, just as if they were ignorant that they had no longer need of them; they tended the grubs in those cells where the eggs had been already hatched, supplying them as usual, from time to time, with Royal Jelly. But at length the new queen in her progress arriving at that side of the comb, she was received by those bees with the same homage and devotion of which she had been already the object at the other side. They approached her, coaxed her with their antennæ and probosces, offered her honey, formed a court circle round her when she was stationary, and a hedge at either side of her path when she moved, and proved how entirely they acknowledged her sovereignty by discontinuing their labour at the royal cells, which they had commenced before her arrival, and from which they now removed the eggs and grubs, and ate the provisions which they had collected in them.

From this moment the queen reigned supreme over the hive, and was treated in all respects as if she had ascended the throne in right of inheritance.

130. Most of the proceedings of these curious little societies are explicable by what seems a general social law among them, to

suffer no individuals or class to continue to exist, save such as are necessary in one way or another to the well-being of the actual community, or the continuance of the species. This principle once admitted, we find explanations satisfactory enough of all the circumstances attending the conduct of the queen regnant towards the royal princesses, of the population generally to the several members of the royal family, and, in fine, of the workers towards the drones.

The royal family, as we have seen, are all fertile females, and their sole function is to assume the throne of the hive itself, or of the colonies called swarms, which successively issue from it, and thus placed to become the fruitful mothers of thousands, which will continue the race and form future colonies.

The drones have no other function than that of kings consort presumptive, either of the hive itself or of the colonies which successively emigrate from it. As has been explained, one only is chosen as consort by each queen. So long as the swarming season continues, a sufficient body of drones are wanted to supply the necessary troop of suitors to each emigrant princess. But when the last swarm of the season has gone forth, and the queen regnant has long since made her choice and celebrated her nuptials, the drones are no longer useful to the general population, and become the objects of a general massacre.

131. After the close of the winter, and at the commencement of the first fine days of spring, the active life of the society recommences. A well peopled hive is then always provided with a fertile queen, who has held the sovereignty since the close of the preceding season. In the months of April and May she begins to lay drone eggs in great numbers. This is called the great laying.

While she is thus engaged depositing her eggs in the larger class of hexagonal cells, previously constructed for their reception, the workers, well knowing that the deposition of royal eggs will speedily follow, occupy themselves in constructing a number of those cells of oval shape and vertical position, (fig. 49,) which have been already described.

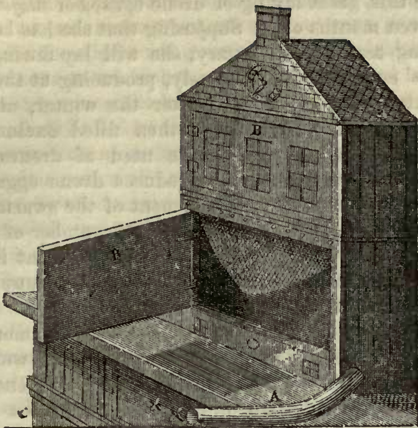


Fig. 56.—THE CABINET BEE-HOUSE.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER V.

132. Change of state of the queen after laying.—133. First swarm led by her majesty.—134. Proceedings of the first swarm.—135. Loyalty and fidelity to the queen—remarkable experiment of Dr. Warder.—136. Interregnum after swarming.—137. The princess royal.—138. Second swarm—its effects.—139. Successive swarms.—140. Production of a factitious queen—Schirach's discovery.—141. Factitious queens dumb.—142. Factitious princesses allowed to engage in mortal combat.—143. Homage only offered to a married queen.—144. Respect shown to her corpse.—145. Functions of the drones.—146. Their treatment.—147. Their massacre described by Huber.—148. Case in which no massacre took place.—149. Character and habits of the workers.—150. Products of their labours.—151. Process of work. 152. Honey and pollen—nectar and ambrosia.—153. Bee the priest who celebrates the marriage of the flowers.—154. Why the bee devotes each excursion to one species of flower.—155. Unloading the workers.—156. Storage of spare provision.—157. Radius of the circle of excursion.

To make this great laying of drone eggs, her majesty must be at least eleven months old. Supposing that she has been hatched the preceding season in February, she will lay during that season workers' eggs almost exclusively, producing at the most from fifty to sixty drone eggs. But after the winter, at the epoch now referred to, the hive being then filled exclusively with workers, and standing in absolute need of drones to supply suitors to the future queens, she produces drone eggs constantly and exclusively until the commencement of the swarming season, with the exception, however, of a limited number of royal eggs, which she deposits at intervals more or less distant in the royal cells just now mentioned, which the workers occupy themselves in constructing during the great laying.

The great laying usually continues for about a month, and it is about the twentieth or twenty-first day that the workers begin to lay the foundations of the royal cells. They generally build from sixteen to twenty of them, and sometimes even as many as twenty-seven. When these cells have attained the depth of two-tenths to three-tenths of an inch, the queen deposits in each of them successively a royal egg. Now since the princesses which are to issue from these eggs are destined to ascend the thrones of the emigrant colonies, which are to issue in succession from the hive, it is important that they should arrive at maturity at successive intervals, corresponding as nearly as possible with the emigration of the swarms.

The queen acts as if she were conscious of this, for she deposits the royal eggs, not like the drone or worker eggs in rapid and uninterrupted succession, but after such intervals as will insure their arrival at maturity in that slow succession, which will correspond nearly or exactly with the issue of the successive swarms.

132. It has been already explained that the nurses seal up the cells, at the time at which the grub is ready to undergo its metamorphosis into a nymph. In accordance with this, and with the successive deposition of the royal eggs, just described, the times of sealing up the series of royal cells are separated by intervals corresponding with those of the deposition of the royal eggs.

Before the commencement of the great laying, the abdomen of the queen is so enlarged that her movements are seriously impeded, and she would be altogether unable to fly. According as the laying proceeds, she becomes smaller and smaller, and when it has been completed, the royal eggs having been meanwhile deposited at regulated intervals, as above described, her majesty recovers her natural form and dimensions, and with them her full bodily activity. This change in the condition of the queen, and

the simultaneous deposition of fifteen hundred to two thousand drone eggs, and some sixteen or twenty royal eggs, are intimately connected with the approaching social state of the colony.

133. It was shown by Huber, and since confirmed by other observers, that it is a constant law of bee politics that the first swarm of the season shall be led by the queen-regnant, who therefore abdicates her native throne in favour of the colonial sovereignty. This swarm takes place when the grub proceeding from the first of the eggs deposited by the queen in the royal cells, as above described, has undergone its transformation into a nymph.* The necessity for this law is thus explained by Huber. Without it, the mutual conflict of the queen-regnant and the princesses, as they would be successively developed, would render the emigration of swarms impossible. For as each princess would issue perfect from the cell, she would be attacked, and forced to engage in combat with the queen, who being, by reason of her age, the stronger and more powerful, would be always victorious. Thus princess after princess would be destroyed, and none would be forthcoming to take the thrones of the successive emigrating colonies. To prevent such a catastrophe, nature has therefore wisely ordered that the queen-regnant, by leading forth the first swarm of the season, should remove all cause of danger to the succession of princesses.

134. When the emigrant swarm thus first sent forth from the parent hive has established itself, the first care of the workers is to construct combs, consisting of workers' cells. They labour assiduously at these, and in accordance with this the queen, who has already deposited in the original hive her full brood of drone eggs, soon begins in her new city to deposit a brood of worker eggs; workers being then the first and most pressing want of the colony. This laying begins as soon as the cells are ready for the deposition of the eggs, and continues for ten or twelve days. About the latter part of this interval, the bees occupy themselves in the construction of the larger class of hexagonal cells for the drone eggs. It would seem as though they knew that her majesty would at this time lay a certain number of such eggs. She accordingly commences laying these, though in far less number than in the great laying, but still sufficient to prepare her people for the succeeding deposition of royal eggs, for which they construct meanwhile a suitable number of royal cells.

It rarely happens, at least in the country where Huber made his observations, that the original queen leads forth a swarm from the new hive. The thing nevertheless occasionally occurs, and when it does, it takes place in three or four weeks after the

* Huber, i. 279.

original swarm, and is attended with circumstances precisely similar.

135. Let us now return to the original hive and see what took place there after the departure and abdication of the reigning queen.

As examples proving the loyalty and fidelity of the bees to their queen, Dr. Bevan quotes some remarkable and interesting cases supplied by Dr. Warder. That apiarist being desirous of ascertaining the extent of the loyal feeling among these little people, hazarded the loss of a swarm in an experiment made with that object. Having shaken on the grass all the bees from a hive which they had tenanted only the preceding day, he carefully sought for and quietly caught the queen. Then placing her with a few attendants in a box, he took her into his parlour, where the lid being removed, she and her attendants immediately flew to the window, when he clipped off one of her wings, returned her to the box and confined her there for more than an hour.

In less than a quarter of an hour the swarm ascertained the loss of their queen, and instead of clustering together in a single mass as usual, like a bunch of grapes, they spread themselves over a space of several feet, were much agitated, and uttered a plaintive sound. An hour afterwards they all took flight and settled upon the hedge where they had first alighted after leaving the parent stock, but instead of clustering together in a single bunch, as when the queen accompanied them, and as swarms usually hang, they extended themselves thirty feet along the hedge in small bunches of forty or fifty or more.

The queen was now presented to them, when they quickly gathered round her with a joyful hum, and formed one harmonious cluster. At night the Doctor hived them again, and on the next morning repeated the experiment to see whether the bees would rise. The queen being in a mutilated state, and unable to accompany them, they surrounded her for several hours apparently willing to die with her rather than abandon her in her distress. The queen was a second time removed, when they spread themselves out again, as though in search of her. Her repeated restoration to them at different parts of their circle produced one uniform result, and these poor loving and loyal creatures always marched and counter-marched every way as the queen was laid. The Doctor persevered in these experiments, till, after five days and nights of voluntary fasting, they all died of inanition except the queen, and she survived her faithful subjects only a few hours.

This remarkable attachment between queen and subjects appears to be reciprocal, the sovereign being as strongly sensible of it as

those over whom she rules. Though offered honey on several occasions during her temporary separation from the swarm in these experiments, she constantly refused it, disdaining a life which was no life to her, deprived of the society of her faithful people.*

136. After the departure of her majesty there seems to be a sort of interregnum in the hive during the succession of swarms. No new sovereign is for the moment elevated to the throne. A strong guard is established at each of the royal cells, whose duty it is to confine the princesses with the utmost rigour to their respective cells, carefully feeding them, and only liberating them at intervals of some days according to the successive departure of the swarms. They are liberated in the strict order of their seniority, the nymph proceeding from the first royal egg, or the princess royal, being invariably the first set free.

137. When she issues forth, her first impulse, like that of all queens, is to fall upon the cells containing her younger sisters to destroy them. This, which in other states of the colony is permitted by the workers, is now strenuously and effectually opposed by them. When she approaches the neighbourhood of the royal cells, the guard in whose charge these are placed, pinch, worry, and hunt her until they compel her to depart, but never attempt to assail her with their stings or seriously injure or disable her.

Now, as there are usually a great number of these royal cells in different parts of the hive, our princess finds it a difficult matter to obtain any corner where she can remain unmolested. Incessantly impelled by her instinct to attack the cells of her sisters, and as incessantly repulsed from them by the surrounding guard, her life is rendered miserable. She is in a constant state of agitation, running from one group of workers to another, until at length the agitation is shared by a certain portion of the workers themselves. When this occurs, a crowd of bees are seen rushing towards the portals of the city. They issue from it accompanied by their young and virgin queen. It is the second swarm of the season, and differs from the first only in the age and condition of its sovereign.

138. After this emigration the workers, who have remained in possession of the hive liberate another of the princesses, the second in seniority, whom they treat exactly in the same manner as the former. The same succession of repulses by the guards of the remaining royal cells takes place, attended by like consequences, this second princess leading forth in the same manner the third swarm, and so on.

139. This spectacle is repeated three or four times in the season

* Bevan, p. 148.

in a well-peopled hive, until the population is so reduced that the number necessary to form a sufficient guard upon the royal cells can no longer be spared from the general industry of the hive. Several princesses then escape from the cells, nearly at the same time, who fall upon each other in the manner already described, being now encouraged instead of being opposed by the workers. In fine, all but one fall in those combats, and this fortunate survivor, who is in general the eldest of the princesses remaining in the hive, ascends the throne, and is acknowledged by the whole community.

According to Huber, swarms issue from the hive only in sunshine and a calm atmosphere. After all the precursors of a swarm have appeared, a passing cloud often arrests it, and the intention of the bees seems to be abandoned. An hour later the appearance of the bright sun will reproduce all the usual movements, and the swarm will issue.

Many conjectures are made as to the means by which the workers know so well, as they undoubtedly do, the relative ages of the several princesses, so as to liberate them according to seniority. Huber conjectures that a peculiar sound, which they produce before their liberation from the cells, and which he thought varied in loudness and pitch, might be the distinguishing character of relative age.

140. A contingency arises occasionally in the bee community, which we have not yet noticed, and which is attended with consequences of a very curious and interesting nature. It was discovered by Schirach, and confirmed by numerous and long continued observations of Huber, that when by any cause a colony loses its queen, without having any royal cells or royal eggs previously provided, they are enabled by certain extraordinary processes and expedients to produce princesses, among whom they may obtain a successor to their last sovereign.

M. Schirach, Secretary of an Apiarian society, at Little Bautzen in upper Lusatia, observed that bees, when shut up with a portion of comb containing worker brood only, would soon construct royal cells, into which they would put worker eggs, the grubs from which, being nourished with royal jelly, would grow up as queens. This remarkable result is known among apiculturers as the Lusatian experiment. This experiment has since been repeated thousands of times, and always with the same results by all the most eminent naturalists who have directed their researches to this part of entomology, and indeed generally by all bee cultivators. So that of the fact itself, strange and incredible as it may seem, there is not the faintest shadow of doubt.

The following is the process by which this miracle of nature is performed.

Having chosen a worker grub, from one to three days old, the workers pull down two of the cells adjacent to that in which the chosen grub lies. They pull down the walls which separate these three chambers, so as to throw them into one three times more spacious than the single cell of the grub. Leaving the pyramidal bases of these three cells untouched, they construct around the grub a large cylindrical tube, which is consequently included within the remaining walls of the three demolished cells, the axis of the tube being parallel to that of the cells, and therefore horizontal.

It seems, however, that to accomplish the desired change on the nature of the grub, it is not only necessary to give it an enlarged cell, but one of which the axis is vertical instead of being horizontal. On the third day, therefore, from the commencement of their operations, they take measures to cement to the horizontal tube a vertical chamber having a conical form, making with the horizontal tube an elbow. To accomplish this they gnaw away several cells below the end of the tube, sacrificing without mercy the grubs which occupy these, as well as those which occupied the two cells adjacent to the original cell of the chosen grub.

This rectangular cell, therefore, composed of the original cylindrical, and the more recently constructed conical cell, may be considered as having some such form as here roughly sketched,

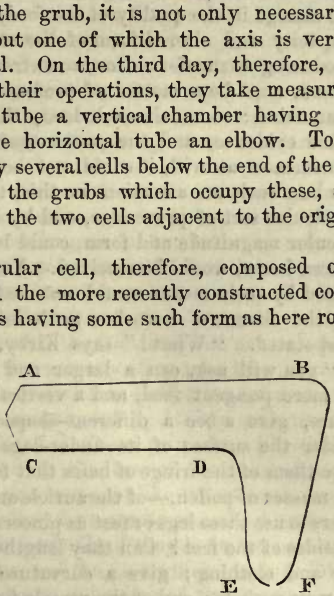


Fig. 53.

(fig. 53,) where ABCD is the horizontal cylindrical part formerly filled by three worker hexagonal cells, and BFED, the vertical conical part, subsequently cemented to it, and built with the wax obtained from the demolition of the worker cells under ABCD.

During two days which the grub inhabits this vertical cell, BFDE, a nurse may always be observed with its head plunged

into it, and when one quits it another takes its place, thus relieving each other with all the regularity of military sentinels. These bees keep constantly lenthening the cell, B F E D, as the grub grows older, and duly supply it with food, which they place before its mouth and round its body. The animal, which can only move in a spiral direction, keeps turning to take the jelly deposited before it, and thus slowly working downwards, arrives insensibly nearer the orifice of the cell, just at the time that it is ready to be metamorphosed into a nymph. At this moment, the workers, conscious of the impending change, seal up the mouth E F of the cell, and cease their attentions, leaving nature to effect the last transformation.

One of these cells is shown at *d*, in fig. 49.

That the mere change in the quality of the food, combined with the increased capacity and altered form of the cradle, should be the means of producing a transformation, so extreme as that from a worker to a queen, must be a matter of profound astonishment to every reflecting mind; so much so indeed, that without the most incontestable evidence, and the power moreover of reproducing the phenomenon at will, it could not be credited. Let any one imagine how such an assertion as this, that the foal of an ass by a particular sort of provender, and by being reared in a stable of particular magnitude and form, could be made to grow into a through bred horse, would be received. Yet, such a transformation produced by such means would not be one whit more wonderful than the change of a worker grub into a queen-bee, by the means just stated. "What!" says Kirby, addressing his correspondent, "you will ask, can a larger and warmer house, a different and more pungent food, and a vertical instead of an horizontal posture, give a bee a different-shaped tongue and mandibles; render the surface of its under-legs flat instead of concave; deprive them of the fringe of hairs that forms the basket for carrying the masses of pollen,—of the auricle and pecten which enable the workers to use these legs or feet as pincers,—of the brush that lines the insides of the feet? Can they lengthen its abdomen; alter its colour and clothing; give a curvature to its sting; deprive it of its wax pockets; and of the vessels for secreting that substance; and render its ovaries more conspicuous and capable of yielding worker and drone eggs?"

In the next place, can the apparently trivial circumstances just mentioned alter altogether the instincts of these creatures? Can they give to one description of animals address and industry, and to the other astonishing fecundity? Can we conceive them to change their very passions, tempers, and manners? That the very same fœtus, if fed with more pungent food, in a higher

temperature, and in a vertical position, shall become a female, destined to enjoy love, to burn with jealousy and anger, to be incited to vengeance, and to pass her time without labour—that this very same fœtus, if fed with more simple food, in a lower temperature, in a more confined and horizontal habitation, shall come forth a worker, zealous for the good of the community, a defender of the public rights, enjoying an immunity from the stimulus of sexual appetite and the pains of parturition—laborious, industrious, patient, ingenious, skilful,—incessantly engaged in the nurture of the young, in collecting honey and pollen; in elaborating wax; in constructing cells, and the like; paying the most respectful and assiduous attention to objects which, had its ovaries been developed, it would have hated and pursued with the most vindictive fury until it had destroyed them! Further, that these factitious queens, thus produced from worker eggs treated as above described, shall differ remarkably from the natural queens proceeding from royal eggs in being altogether mute! All this must seem so improbable, and next to impossible, that it would require the strongest and most irrefragable evidence to establish it.*

141. It will be remembered that the princesses, when forcibly confined to their native cells by the workers on guard over them, after they have undergone the last transformation, utter a peculiar sound, to the varieties of which Huber ascribes the power of the workers to determine their relative ages. Kirby in the observations just quoted, refers to this, when he indicates one of the distinctions between the factitious and natural queens, the former never uttering these or any other sounds.

142. Another remarkable distinction between the factitious and natural queens is indicated by Huber; no guard is kept at the doors of the cells of factitious princesses, like that which has been already described in the case of the cells of natural princesses. The factitious princesses, unlike the natural, are not detained in their cells after they have undergone the last transformation, but are allowed to issue forth, if they have not been already destroyed by the jealous rage of the first which comes to life.

This peculiarity in the policy of the hive may be explained by the fact, that while the natural princesses are wanted to take the sovereignties of the successive swarms, the factitious ones are only produced to meet the extraordinary emergency of the hive being deprived of its queen, leaving behind her no royal brood, and since only one queen is wanted, the factitious princesses are allowed, and indeed encouraged, by the workers to engage in

* Kirby, Int., vol. ii. 110.

martial conflict until one only survives, who assumes the throne of the hive.

143. The circumstances and anecdotes related by observers illustrative of the affection, devotion, and respect manifested towards the queen by her subjects are innumerable. In addition to those which we have already given, the following will be read with interest.

All the devotion, it must be observed, commences only after the royal nuptials. A virgin queen is treated with indifference the most absolute. But after her marriage has been celebrated, and she presents herself to her subjects in the double character of sovereign and mother, they more than respect her. "They are," says Reaumur,* "constantly on the watch to make themselves useful to her, and to render her every kind office. They are for ever offering her honey. They lick her with their proboscis, and wherever she goes she has a court to attend her."

144. The same naturalist relates that even the inanimate body of the queen is an object of tenderness and affection to the bees. He took one out of the water quite motionless and seemingly dead. It was also mutilated, having lost part of one of its legs. Bringing it home, he placed it among some workers that he had found in the same situation, most of which he had recovered by means of warmth, some, however, being still in as bad a state as the poor queen. No sooner did these revived workers perceive the latter in this wretched condition than they appeared to compassionate her case, and did not cease to lick her with their tongues till she showed signs of returning animation; which the bees no sooner perceived than they set up a general hum as if for joy at the happy event. All this time they paid no attention to the workers, who were in a most miserable condition.†

145. In the economy of the bee, there is nothing which presents more difficulty to the naturalist than the satisfactory explanation of the functions of the drones. These, as has been already explained, are the sole male members of the society; the queen being the sole fertile female; and the workers, though female, exercising none of the functions of that sex, and being limited to the industrial and parental duties of the society. The number of drones in a single society is from 1500 to 2000, one only of whom can enjoy the honour of elevation to the distinguished position of king consort, and that one, as already explained, never surviving the day of the nuptials. What then, it may well be asked, are the services rendered to the community by these hundreds of consumers of the products of the industry of the society? They never themselves take part in the common labours. They neither

* Reaumur, v. 262. † Reaumur, v. 265.

collect food nor materials, nor do they aid in any way in the construction of the dwellings, nor in the care or nurture of the young. In the absence of any better explanation of their vast number it has been said that the purpose is to insure a consort to the queen. But surely this object might be effected without encumbering the society with 2000 candidates for the royal favour.

It has been suggested by some apiarists that the drones may sit upon the eggs, and by others that their use may be to develope heat sufficient to maintain the hive at the necessary temperature; but the experiments and observations of other naturalists have set aside these hypotheses.

146. Whatever be the purpose which this section of the society is destined to fulfil, their treatment by the people, and the manner in which their existence is terminated, are remarkable.

So long as swarms continue to issue from the hive, drones are wanted to supply the necessary proportion of that class to accompany them. But after the swarming season closes, which in these climates it generally does towards the end of July, at least in dry summers, the general massacre of the drones takes place. At that time the bees are seen hunting them in all parts of the hive, and driving them to the base upon which it stands. Soon after this the stand and the ground before the hive are found to be covered with the bodies of hundreds of the murdered drones. It was supposed by Bonnet that no direct massacre was executed, but that the drones driven from the stores of their food died of starvation.*

147. Huber, however, among his other numerous discoveries, contrived to witness, through the eyes of his faithful Burnens, the actual massacre.

At the season at which the extermination usually took place, he placed upon plates of glass six populous hives occupied by swarms of the preceding year, and Burnens lying on his back under the hives was enabled to witness all that took place by the transparency of their bases. On the 4th of July, 1787, he witnessed the massacre, which took place at the same hour in all the six hives. The base was crowded with bees, who appeared in a state of great excitement. As fast as the drones, hunted by other bees from the superior parts of the combs, arrived at the base, the bees there assembled fell upon them, seizing them by their antennæ, legs, or wings, and after dragging them about with apparent rage, put them to death by stabbing them with their stings between the segments of the abdomen. The moment they were thus pierced, they spread their wings and expired. However,

* Bonnet, "Contemplation de la Nature," chap. xxvi. part. xi.

as if the workers did not feel sufficiently certain of their fate, they continued to pierce their bodies with their stings, and often drove these formidable weapons in so deep that they could only extricate them by unscrewing them in the manner already described (126).

The next day they resumed their observations, when a most curious spectacle presented itself. During three hours they saw the massacre of drones, which had been resumed with the same fury, continued. On the preceding day they had exterminated all the drones of their own hives; but this time their attack was directed against those of neighbouring hives, which, having fled, had taken refuge in these, after the massacre of the preceding day had been concluded.

Not content with this complete extermination of the drones themselves, the workers resorted to the cells in which drone nymphs were contained, which had not yet completed their final transformation. These they pitilessly dragged forth, killed, sucked the juices contained in their bodies, and then flung the carcasses out of the hives.

148. It was also ascertained by Huber, that in hives deprived of their queen, or in which the queen, by reason of retarded fecundation, only laid drone eggs, no massacre ever took place. In such hives the drones not only find a sure refuge, but are carefully nurtured and fed.

This circumstance, combined with the fact that the massacre never takes place until after the swarming season is over, seems to indicate the functions of the drones. They are useful only where candidates for the royal nuptials are likely to be wanted.

149. The most interesting class of the bee community is also that which is by far the most numerous, the workers. Indeed, to this class all others must be regarded as subordinate, just as in human societies all are dependent on the producing classes. Much respecting their character, habits, and manners, in relation to the care of their young, and the construction of the city, in a word in respect to their internal labours, has been already explained. Something now must be said of their external industry, directed to the collection of provisions for the community, young and old, and of the materials necessary for the prosecution of all their various works, labours which have been illustrated by Professor Smyth in the following beautiful lines:—

"Thou cheerful bee! come, freely come,
And travel round my woodbine bower;
Delight me with thy wandering hum,
And rouse me from my musing hour.

Oh ! try no more those tedious fields,
Come taste the sweets my garden yields ;
The treasures of each blooming mine,
The bud, the blossom—all are thine.

" And, careless of this noontide heat,
I'll follow as thy ramble guides ;
To watch thee pause and chafe thy feet,
And sweep them o'er thy downy sides ;
Then in a flower's bell nestling lie,
And all thy envied ardour ply !
And o'er the stem, though fair it grow,
With touch rejecting, glance and go.

" Oh, Nature kind ! Oh, labourer wise !
That roam'st along the summer's ray,
Glean'st every bliss thy life supplies,
And meet'st prepared thy winter day !
Go, envied, go—with crowded gates
The hive thy rich return awaits ;
Bear home thy store, in triumph gay,
And shame each idler of the day."

150. The immediate objects to which the exterior industry of the bee is directed, are *nectar*, *pollen*, and *propolis*.

Nectar is a specific juice, found in certain classes of flowers, from which the bee elaborates honey and wax.

Pollen is a peculiar powder, or dust, spread over the anthers of flowers, which constitutes the principle of fecundation of the flowers themselves, and is the material of which the bee makes bread, which serves as food both for old and young.

Propolis is a resinous substance, evolved by certain vegetables which the bee uses as cement, mortar, or glue, in its architecture. When the bee pierces the vessels of the flowers, which, containing nectar, are called nectarines, and swallows that precious juice, it is deposited provisionally in the honey-bag already described (26) ; sometimes called, on that account, the first stomach. Here this nectar is converted into honey, the chief part of which is regurgitated, to be stored up for future general consumption in the honey-cells of the combs.

In the stomach, properly so called (26), and in the intestines, the bread only is found.

How the wax is secreted, physiologists have not yet discovered with any certainty. It is evident, however, that the immediate seat of its production is within the abdomen, since the parts called wax-pockets, from which it is externally evolved, are rendered visible by pressing the abdomen so as to make it extend itself. A pair of quadrangular whitish pockets, of soft membranaceous texture, will then be seen on each of the four middle ventral,

segments. On these the plates of wax are formed, and are found upon them in different states so as to be more or less perceptible.

151. Observe a bee, says Kirby, that has alighted on a flower. The hum produced by the motions of her wings ceases, and her work begins. In an instant she unfolds her tongue, which was previously rolled up under her head. With what rapidity does she dart this organ between the petals and the stamina! At one time she extends it to its full length, then she contracts it; she moves it about in all directions, so that it may be applied to the concave and convex surface of the petal, and sweep them both, and thus by a virtuous theft, she robs it of all its nectar. All the while this is going on, she keeps herself in a state of constant vibratory motion.

Flowers, though the chief, are not the only sources from which the bee derives the material of honey and wax. She will also eat sugar in every form, treacle, the juice secreted by aphides; and, in fine, the juice of the bodies of nymphs and of eggs of bees themselves, as already explained.

152. When the industrious little creature has filled its honey-bag with nectar, it proceeds to collect the pollen, of which it robs the flowers by brushing it off with the feathery hairs with which its body is covered. As the honey is called the NECTAR, so this pollen, or the substance bee-bread, into which it is converted, may be called the AMBROSIA of the hive. Together they constitute the food and the drink of the population.

When the bee has so rolled itself in this farina of the blossoms of the garden and the field, that its whole body is so powdered with it, as to give it the peculiar colour of the species of flowers to which it happens to resort, it suspends its excursions, and sets about to brush its body with its legs, which, as already explained, are supplied with brushes for this express purpose. Every particle of the flower thus brushed off is most carefully collected and kneaded up into two little masses, which are transferred from the fore to the hind legs, and there packed up into the baskets provided for its reception and transportation.

Naturalists generally are of opinion that in each of its excursions a bee confines its foraging operations to a single species of flower. This explains the fact that the colour of their load after such excursions is uniform, depending on the particular species of flower which they have robbed of its sweets. Thus, according to Reaumur, some bees are observed to return loaded with red pellets on their thighs, others with yellow, others whitish, and others with green.

Kirby observes, that it seems probable that the bee confines its operations in such excursions to flowers of the same species, and

that the grains of pollen which enter into the same mass should be homogeneous, and consequently fitted by their physical properties to cohere with greater facility and firmness.

153. But connected with this, another important purpose of nature is fulfilled, which must not here pass without special notice. The principle, so fruitful in important social consequences among animals, that the offspring owes its parentage jointly to two individuals of different sexes, or, in other words, must always have a father and a mother, equally prevails in the vegetable kingdom. There also are the gentlemen and ladies, there also are the loves which unite them, loves which as well as those of superior orders of beings have supplied a theme for poets.* Now among the many other interesting offices with which the Author of nature has invested the little creatures, which form the subject of this notice, not the least singular is that of being the priests who celebrate the nuptials of the flowers. It is the bee literally which joins the hands and consecrates the union of the fair virgin lily and the blushing maiden rose with their respective bridegrooms. The grains of pollen which we have been describing are these brides and bridegrooms, and are transported on the bee from the male to the female flower; the happy individuals thus united in the bands of wedlock being the particular grains, which the bee lets fall from its body on the flower of the opposite sex, as it passes through its blossom.

154. And here we find another circumstance to excite our admiration of the wise laws of that Providence, which cares for the well-being of a little flower, as much as for that of a great lord of the creation. If the bee wandered indifferently from flower to flower without selection, the gentlemen of one species would be mated with the ladies of another, hybrid breeds would ensue, and the confusion of species would be the consequence. But the bee, as knowing this, flies from rose to rose, or from lily to lily, but never from the lily to the rose, or from the rose to the lily.

155. When a bee, laden with pollen, arrives in the hive, she sometimes stops at the entrance, and leisurely detaching it piecemeal from her legs, devours it bit by bit. Sometimes she passes into the hive and walks over the combs, or stands stationary upon them, but whether moving or standing never ceases flapping her wings. The noise thus produced, a sort of buzzing, seems to be a call understood by the populace within hearing, for three or four of them immediately approach and surround her. They begin to aid her to disembarrass herself of her load, each taking and swallowing more or less of her ambrosia until the whole is disposed of.

* Darwin's Loves of the Plants.

156. When more pollen has been collected than the society wants for present use, it is stored up in some of the unoccupied cells. The bee, laden with it, puts her two hind legs into the cell, and with the intermediate pair pushes off the pellets. When this is done she, or another bee if she be too much fatigued, enters the cell head-foremost and remains there for some time, during which she is occupied in diluting, kneading, and packing the bee-bread; and so they proceed one after another, until the cell has been well packed and filled with the store of provisions. In some combs a large portion of the cells is filled with this ambrosia, in others, cells containing it are intermixed with those filled with honey or with bread. It is thus everywhere at hand for use.*

The propolis, the third object of bee industry, is collected from various trees, and especially from certain species of the poplar. It is soft and red, will allow of being drawn out into a thread, is aromatic, and imparts a gold-colour to white polished metals. It is employed in the hive, as already stated, not only in finishing the combs, but also in stopping up every chink and orifice by which cold, wet, or any enemy could enter. They coat with it the chief part of the inner surface of the hive, including that of the sticks placed there for the support of the comb. It is carried by the bees in the same manner as is the pollen on the hind legs.

157. The radius around their habitation, within which the bee industry is confined, is differently estimated, being according to some a mile, and according to others extending to a mile and a half. Various experiments prove that it is by their scent that the bees are guided to the localities where their favourite flowers abound.

* Kirby, Int., ii. 151.

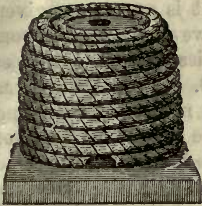


Fig. 63.—Scotch hive.

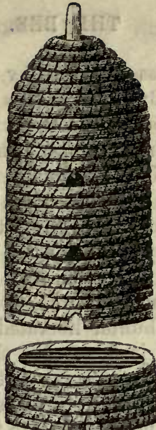


Fig. 64.—Radouan's hive.

Fig. 65.—Cork hive (South of France).

THE BEE.

CHAPTER VI.

158. How they fly straight back to the hive—manner of discovering the nests of wild bees in New England.—159. Average number of daily excursions.—160. Bee pasturage—transported to follow it—in Egypt and Greece.—161. Neatness of the bee.—162. Its enemies.—163. Death's-head moth.—164. Measures of defence adopted by Huber.—165. Measures adopted by the bees.—166. Wars between different hives.—167. Demolition of the defensive works when not needed.—168. Senses of insects.—169. Senses of the bee.—170. Smell.—171. Experiments of Huber.—172. Remarkable tenacity of memory.—173. Experiments to ascertain the organ of smell.—174. Repugnancy of the bee for its own poison.—175. Their method of ventilating the hive.—176. Their antipathy against certain persons.—177. Against red and black-haired persons.—178. Difference of opinion as to the functions of the antennæ.—179. Organs of taste.—180. Hearing: curious anecdotes.—181. Vision.—182. Peculiar characters of queens; royal old maid.—183. Drone-bearing queens.—184. Change of their instincts and manners.—185. Their treatment by the workers.—186. Nuptials never celebrated in the hive.—187. Effect of amputating the royal antennæ.

158. One of the many wonders presented by their economy is the directness and unerring certainty of their flight. While collecting their sweets they fly hither and thither, forward or backward, and right or left, as this or that blossom attracts them; but when fully laden with the spoil, though upwards of a mile from their city, they start for it in a course more exact than if they were guided

by a rudder and compass, governed by the hand of the most consummate navigator. By what means this is accomplished has never been explained, but connected with it is an account given in the "Philosophical Transactions" which we cannot refrain from quoting here. "In New England a species of wild hive-bees abounded in the forests about the year 1720. The following was the method practised for discovering their nests and obtaining their honey. The honey-hunters set a plate containing honey or sugar, upon the ground on a clear day. The bees soon discovered and attacked it. Having captured two or three who had thus gorged themselves, the hunter liberated one of them and marked the direction in which it flew. He then changed his position, walking in a direction at right angles to the course of the bee to a distance of a few hundred feet, where he liberated another of his little captives, and noted as before the direction of its flight. The point where the two directions thus obtained, intersected, was of course that to which both bees had directed their course, and there the nest was always found."

159. The industry of the bee may be estimated by the average number of its daily excursions from the hive to collect provisions. According to Reaumur, if the total number of excursions be divided by the total number of bees in a hive, the average number daily made by each bee would be from five to six. But as one-half of the bees are occupied exclusively with the domestic business of the society, either in nursing and tending the young, packing and storing the provisions, or constructing the combs, the total number of excursions must be divided, not between the whole, but between only half the total number of bees, which would give ten excursions to each individual of the collecting class; and if the average length of each excursion be taken at three quarters of a mile, this would give the average distance travelled by each collector as fifteen miles! It is estimated by Kirby that the quantity of ponderable matter thus transported during a season in a single hive would be about 100 lbs. "What a wonderful idea does this give of the industry and activity of those useful little creatures! and what a lesson do they read to the members of societies, that have both reason and religion to guide their exertions for the common good! Adorable is that Great Being who has gifted them with instincts which render them as instructive to us, if we will condescend to listen to them, as they are profitable." *

160. The plants and flowers which form the pasturage of the bees are, in many countries, produced at different places at different seasons of the year; and where the bees in a particular neigh-

* Kirby, Int., ii. 155.

bourhood are numerous, the pasturage surrounding their hives often becomes exhausted. In such cases the agriculturists transport the bees from localities which they have exhausted, to others in a state of comparative abundance, just as the shepherd drives his sheep from field to field, according as the pasturage is eaten down. In Egypt, towards the end of October, when the inundations of the Nile have ceased, and the husbandmen can sow the land, saintfoin is one of the first things sown; and as Upper is warmer than Lower Egypt, the saintfoin gets there first into flower. At this time bee-hives are transported in boats from all parts of Egypt into the upper district, and are there heaped in pyramids upon the boats prepared to receive them, each being marked with a number which indicates its owner. In this station they remain for some days, and when it is considered that they have pretty well exhausted the surrounding fields of their sweets, they are removed a few leagues lower down, where they are retained for a like interval; and so they descend the river, until towards the middle of February they arrive at its mouth, where they are distributed among their respective proprietors.*

A similar practice prevails in various parts of the East and in Greece. The inhabitants of the towns are often the proprietors of fifty or sixty hives, the product of which forms an article of their trade. The hives are sent in the season when the herbage is in flower to the various rural districts, being sealed up by the owner, the small bee-door only being open, and are given in charge to the villagers, who at the close of the season are paid for their care of them. Ranges, consisting of five or six hundred hives, are often seen thus put out to grass.†

161. Bees are remarkable for neatness and cleanliness, both as to their habitations and their persons. They remove all dirt and nuisances from their hive, with the regularity of the neatest housewives. When their strength is insufficient for this, they contrive various ingenious expedients to abate the nuisance. If snails find their way into the hive, as they sometimes do, they kill them with their stings; and in order to prevent noisome and unwholesome effluvia from their decomposing remains, they embalm them with propolis. If the snail is protected from their stings by its shell, they bury it alive in a mass of propolis.

When pressed by natural wants, they do not defile their habitation by relieving themselves in it, but go abroad for the purpose.

When a young bee issues from the cell, a worker immediately approaches, and, taking out its envelope, carries it out of the hive; another removes the exuviæ of the larva, and a third any

* Reaumur, v. 698.

† Willock, in "Gardeners' Chronicle, 1841, p. 84.

filth or ordure that may remain, or any pieces of wax that may have fallen in when the young bee broke through its cocoon. But they never attempt to remove the silk lining of the cell spun by the larva in its first transformation, because that, instead of being a nuisance, gives increased solidity and ornament to the cell.

162. Notwithstanding the amiable character and excellent political organisation of the bees, these little people have numerous enemies, with some of whom they are often compelled to wage offensive wars, and against others to fortify themselves, by expedients and with skill, which will bear comparison with the operations of the most consummate military engineers. Sebastopol itself was not more ingeniously defended by its outworks than, in certain cases, bee-hives are.

From the curious account which Latreille has given us of *Philanthus aviporus*, a wasp-like insect, it appears that great havoc is made by it of the unsuspecting workers, which it seizes while intent upon their daily labours, and carries off to feed its young.

163. Another insect, which one would not have suspected of marauding propensities, must here be introduced. Kuhn informs us, that long ago (in 1799) some monks who kept bees, observing that they made an unusual noise, lifted up the hive, when an animal flew out, which, to their great surprise, no doubt, for they at first took it for a bat, proved to be the death's-head hawk-moth (*Acherontia atropos*), already celebrated as the innocent cause of alarm; and he remembers that several, some years before, had been found dead in the bee-houses. M. Huber also, in 1804, discovered that it had made its way into his hives and those of his vicinity, and had robbed them of their honey. In Africa, we are told, it has the same propensity; which the Hottentots observing, in order to monopolise the honey of the wild bees, have persuaded the colonists that it inflicts a mortal wound.

This moth has the faculty of emitting a remarkable sound, which he supposes may produce an effect upon the bees of a hive, somewhat similar to that caused by the voice of their queen, which as soon as uttered strikes them motionless, and thus it may be enabled to commit with impunity such devastation in the midst of myriads of armed bands.

The larvæ of two species of moth (*Galleria cereana* and *Mellonella*) exhibit equal hardihood with equal impunity. They, indeed, pass the whole of their initiatory state in the midst of combs. Yet, in spite of the sting of the bees of a whole republic, they continue their depredations unmolested, sheltering themselves in tubes made of grains of wax, and lined with silken tapestry, spun and woven by themselves, which the bees (however disposed they may be to revenge the mischief which they do to them, by

devouring what to all other animals would be indigestible—their wax) are unable to penetrate. These larvæ are sometimes so numerous in a hive, and commit such extensive ravages, as to force the poor bees to desert it and seek another habitation." *

164. Huber gives the following most interesting account of the measures taken by his bees, to fortify themselves against the incursions of the death's-head moth.

When he found his hives attacked and their store of honey pillaged by these depredators, he contracted the opening left for the exit and entrance of the bees to such an extent, as while it allowed them free ingress and egress, it was so small that their plunderers could not pass through it. This was found to be perfectly effectual, and all pillage was thenceforward discontinued in the hives thus protected.

165. But it happened that in some of the hives this precaution was not adopted, and here the most wonderful proceeding on the part of the bees took place. Human contrivance was brought into immediate juxtaposition with apiarian ingenuity.

The bees of the undefended hives raised a wall across the gate of their city, consisting of a stiff cement made of wax and propolis mixed in a certain proportion. This wall, sometimes carried directly across and sometimes a little behind the door, first completely closed up the entrance; but they pierced in it some openings just large enough to allow two bees to pass each other in their exits and entrances.

The little engineers did not follow one invariable plan in these defensive works, but modified them according to circumstances. In some cases a single wall, having small wickets worked through it at certain points, was constructed. In others several walls were erected one within the other, placed parallel to each other, with trenches between them wide enough to allow two bees to pass each other. In each of these parallel walls several openings or wickets were pierced, but so placed as not to correspond in position, so that in entering a bee would have to follow a zigzag course in passing from wicket to wicket. In some cases these walls or curtains were wrought into a series of arcades, but so that the intervening columns of one corresponded to the arcades of the other.

The bees never constructed these works of defence without urgent necessity. Thus, in seasons or in localities where the death's-head moth did not prevail, no such expedients were resorted to. Nor were they used against enemies which were open to attack by their sting. The bee, therefore, understands

* Kirby, vol. i. p. 130.

not merely the art of offensive war, and can play the part of the common soldier, but is also a consummate military engineer; and it is not against the death's-head moth alone that it shows itself capable of erecting such defences.

166. Thinly peopled hives are sometimes attacked by the population of other bee cities. In such cases, incapable of immediate defence by reason of their inferior numbers, they erect similar fortifications, but in this case they make the wickets in the walls so small that a single worker only can pass through them; and a small number stationed on the inside of these openings, are accordingly sufficient to defend the hive against the attack of large besieging armies.

167. But when the season for swarming arrived, these works of defence, whether constructed against the invasion of the moth or hostile bees, became an impracticable obstruction to the exit of the succession of emigrating colonies, and were therefore demolished, and were not reconstructed without pressing necessity. Thus the works constructed in 1804 against the invasions of the moth were taken down in the swarming season of 1805; and as the plunderers did not re-appear in that year, they were not re-erected. But in the autumn of 1807, the moths appearing in great numbers, the bees immediately erected strong barricades, and thus effectually prevented the disaster with which their population was menaced. In the next swarming season, in May 1808, these works were again demolished.

It ought to be observed, that whenever the door of the hive is itself too small to admit the moth, the bees erect no defences against it.*

168. One of the most interesting and, at the same time, most difficult question connected with the faculties of insects, is that of the number and nature of their senses. It has been often and truly said, that no being, however intelligent, can form even the most obscure notion of a sense of which he is himself deprived. The man deprived of sight, to whom the colour scarlet was elaborately described, said that his notion of it was that of the sound of a trumpet. Granting then the possibility that insects may be endowed with a peculiar sense, or mode of perception, of which we are destitute, we are in no condition to form a conception of the power or impressions of such a sense, any more than the blind man was who attempted to acquire a conception of a red colour.

But without supposing the possible existence of peculiar senses independent of the five with which we are endowed, it may be that the very organs which we possess may be given with an infi-

* Huber, ii. 293—298.

nitely higher degree of sensibility to these minute species. Their auditory organs may be such as to give them the power of ear-trumpets, and their eyes may be either microscopic or telescopic, or both united. Their olfactory organs may have a susceptibility infinitely more exalted than ours, as indeed innumerable facts prove those of many species of inferior animals to be. Art and science have supplied us with numerous tests, by which the physical properties of substances are distinguished, by characters which escape all our senses. Why may not the Creator have given to inferior animals specific organs, capable of perceiving those distinctions, as surely and promptly as the eye distinguishes shades of colour, the nose varieties of odour, or the ear the pitch of a musical note?

169. Among social insects, the hive-bee stands preeminent for the manifestation of sensitive faculties. Sight, touch, smell, and taste, are universally accorded to it. Hearing was regarded as doubtful, but we have shown that a noise produced at any side of a hive, will immediately bring there the queen and her court, to see what is the matter.

But if the sensibility of the ear be doubted, what exaltation of power do we not find in the eye! How unerring is the perception of her dwelling, while the bee lies at distances and under circumstances, which might well appear to baffle the most acute human organ, aided even by human intelligence! The little bee, issuing from her hive, departs upon her industrial excursion, and flies straight to the field which she has already discovered to be most fertile of honey flowers. Her route to it is as straight as the flight of a bullet from a gun to the object aimed at. When she has gathered her load, she rises in the air, and, flying back to her hive with the same unerring certainty, finds it among many, and entering it, finds the cells which are appropriated to her care.

The sense of touch is, perhaps, even more to be admired than that of sight, for it supplies the place of that sense in the darkness of the internal labyrinth of the hive. In darkness the architecture of the combs is constructed, the honey is stored in the cells appropriated to it, the young are nourished, their food being varied with their respective ages, the queen is recognised,—and all this appears to be accomplished by some sensitive power possessed by the antennæ, organs whose structure, nevertheless, seems to be incomparably inferior to that of the human hands.

The industrial activity of the bee is much less excited by warm weather and bright sunshine, than by the prospect of collecting an abundant supply of provisions for the hive. When the lindens and the buck-wheat are in flower, they brave the rain

and cold, commencing their excursions before sunrise, and continuing their work much later than their customary hours. But when the flowers rich in pollen and nectar prevail in less abundance, and when the scythe has swept away the flowers which enamelled the fields, even the brightest sunshine and the warmest days fail to attract the industrious population to go abroad.

170. Of all the senses of the bee, that of smell appears to be the most acute. Certain odours have an irresistible attraction for the insect, while others are in the same degree repugnant to it. Of the former, as might naturally be expected, honey is by far the most exciting. It was supposed by Huber, not without much probability, that the bee is attracted to this or that flower, not by its colour, form, or other visible properties, but by the odour of the nectar it contains. To test this experimentally, Huber put some honey in a box, so as to be invisible from the outside, and placing it in the neighbourhood of his hives, found that the bees crowded round it in a few minutes, finding their way to the honey through a small hole left for the purpose.

171. He next made several small entrance holes in a box containing honey, but covered each hole with a sort of card valve, such that it would be possible for a bee to raise it and enter the box. The box thus prepared was placed at two hundred yards from the hives. In half an hour the bees found it, crowded in great numbers on every side of it, examining carefully every part, as if to seek for an entrance. At length, finding the valves, they set to work at them, and never ceased until they succeeded in raising them, when they entered and took possession of the spoil.

How exquisitely acute must be their olfactory organs will be apparent, when it is considered that, in this case, the box and valves must have confined very nearly the whole effluvia of the honey.

172. The following remarkable proof of the tenacity of memory with which the bee is endowed, is given by Huber. A supply of honey had been placed in autumn upon an open window. The bees had the habit of coming to feast upon it. This honey being removed, the window was closed, and remained closed during the winter. In the following spring the bees again found their way to the same window, expecting again to find a supply there, although none had been placed there. It is evident in this case, that the insect must have been guided by its memory alone, and that it was capable of retaining a recollection of places and circumstances for several months.

173. Huber made several curious and interesting experiments to determine the seat of the sense of smell. If, as was natural to expect, it were situate in some of the appendages of the mouth,

it would be deadened by stopping these, as we defend ourselves from a noisome odour by stopping the nose. Catching several bees he, therefore, held them while he stopped their mouths and probosces with flour-paste, and liberating them when the paste was hardened, he found that they no longer showed any sign of the possession of a sense of smell. They were neither attracted by honey, nor repelled by objects whose odours were known to be most repugnant to them.

174. Among the substances to whose odour the bee shows the strongest repugnance, is its own poison. This was demonstrated by Huber by very remarkable experiments. Having provoked the insect to put forth its sting, and eject its poison, he presented this offensive juice on the end of a sharp instrument to some worker bees, which were quietly resting at the door of their hive. A general agitation was immediately manifested among them. Some launched themselves on the poisoned instrument, and others fell upon the individual who held it. That it was not the instrument itself which in this case provoked their rage, was proved by the fact, that a similar one, bearing no poison, being presented to them, did not produce any effect.

175. An inconvenient elevation of temperature and want of ventilation will sometimes impel the bees to leave their combs, but if they are excited to remain upon them by the want of feeding, they know how to reconcile the conflicting impulses. In that case they produce coolness and change of air without deserting the provisions which surround them, or the care of their young. A certain number of the insects begin to flap their wings, which are thus used as fans, producing currents of air. But as they are not able to sustain this labour for an indefinite time, they take it by turns, regularly relieving each other.

To try what the conduct of the bees would be, if by artificial means the ventilation of the hive were so impeded that the usual small number of *fanners* would not suffice, Huber submitted hives to such unusual conditions, and found that in such cases the number of bees flapping their wings was augmented in the same proportion as the ventilation was impeded, until at length the whole population of the hive were thus occupied.

176. The antipathy which bees manifest against particular individuals, is generally ascribed to some odour proceeding from their persons to which the insect bears a repugnance. M. de Hafor, of the Grand Duchy of Baden, had been for many years an assiduous cultivator and amateur of bees, and was on such friendly terms with them that he could at all times approach them with impunity. He would, for example, put his fingers among them, select the queen, and taking hold of her, place her on the palm of his

hand. It happened that this gentleman was attacked with a violent and malignant fever, which long confined him to his bed and his house. Upon his recovery he, naturally enough, revisited his old friends the bees, and began to caress them and renew his former familiarity.

He found, however, to his surprise and disappointment, that he was no longer in possession of their favour, and instead of being received as formerly, his advances were resented as an unwelcome and irksome intrusion; nor was he ever afterwards able to perform any of the usual operations upon them, or to approach them without exciting their rage.

177. According to Dr. Bevan and M. Feburier, both close and accurate observers of the habits of the insect, red and black-haired persons are peculiarly obnoxious to it. Feburier mentions a mastiff to which his bees had a particular aversion, pursuing him into the house with such pertinacity, that doors and windows were obliged to be closed for his protection.

Dr. Bevan mentions that he had two friends, brothers, one of whom was so inoffensive to the bees, that he could stand with impunity over the hive and watch all their doings, while the other could scarcely enter the garden with impunity.

178. The antennæ are generally regarded as the proper organs of the tactile sense, and hence are popularly, though not properly, called feelers,—the feelers being in fact the palpi already mentioned. Naturalists are not agreed as to the functions of the antennæ, though all concur as to their importance. Some consider them as organs of smell, others as organs of hearing; while others claim for them the place of organs of a sixth sense, of which man and the higher animals are destitute. This sense is considered by Kirby as an intermediate faculty between sight and hearing, rendering the insect sensible of the slightest movement of the circumambient air. Dr. Evans, as quoted by Dr. Bevan, in reference to the faculty conferred on the bee by the antennæ, says,—

> "The same keen horns, within the dark abode,
> Trace for the sightless throng a ready road;
> While all the mazy threads of touch convey
> That inward to the mind, a semblant day."

The antennæ, and the two pair of palpi, would seem to have correlative and complementary functions: they are both in constant motion. The palpi are in reality the feelers, in the proper sense of the term; as is apparent by observing the manner in which the insect applies them to the food before eating it.

179. Cuvier considers the organs of taste in the bee to constitute one of its most important characters. The sensibility of these

organs is manifested by the delicate choice of food which the insect makes, showing a preference for those flowers, wherever they can be found, which yield the finest honey. Hence the celebrity of the honey of Narbonne, Hymettus, Hybla, and Pontus.

180. Numerous indications show that the bee possesses the sense of hearing. The manner in which they are attracted to any quarter of the hive where an unusual noise is produced, has been already mentioned. Dr. Bevan mentions some curious examples of their power of hearing, and even of the sense they seem to attach to particular vocal sounds. Thus he mentions an old dame of his acquaintance, who was a very fearless operator in the treatment of these insects, and who used to suppress any movement of anger on the part of the bees merely by saying to them, "Ah! would you dare?" A servant of Mr. Knight, the well-known apiarian, used to quell their anger by exclaiming, "Get along, you little fools!"

Some difference of opinion has nevertheless prevailed as to the existence of this sense in insects. The opinion of Linnæus and Bonnet was against it. Many evidences, however, may be adduced in favour of its existence. Thus, one grasshopper will chirp in response to another, and the female will be attracted by the voice of the male. Brunelli shut up a male in a box, and allowed the female her liberty; as soon as the male chirped she flew to him immediately. A bee on the window within a bee-house will make a responsive buzz to its fellows on the outside.*

181. The indications of a keen sense of vision, in the certainty and precision with which the bee flies to its pasturage and back to its hive, have been already mentioned. Naturalists, however, are not agreed as to the particular power of the eyes of these insects. Some, for example, contend that their sight is extremely short, and that

> Its feeble ray scarce spreads
> An inch around;

while others contend that its vision of near objects is obscure and imperfect, but for distant ones quite distinct. Thus Butler and Wildman say that they have observed the bees go up and down seeking the door of the hive, as if they were in the dark; but Bevan observed that they easily discovered it by rising on the wing, and thus throwing themselves at a greater distance from it.

182. Among the mysteries of the social economy of the bee, there is perhaps nothing more curious than the circumstances which, in certain cases, appear to affect the personal character of the

* Bevan, p. 362.

sovereign. We have already explained that there are certain periods in the life of the queen, during which she produces eggs of certain sorts,—at one period those only of workers, at another those only of drones. But if the epoch of her nuptials be postponed to a certain advanced period of life, at which, if we may be allowed the expression, she begins to approach the condition of an *old maid*, a singular change is found to have taken place in her constitution, in consequence of which she is no longer capable of having any but *male offspring*, in other words, she is incapable of laying any but drone eggs.

183. Now since such a queen is obviously incapable of discharging those functions, which are indispensable to the continuance of the population over which she presides, and of whose young she ought, in the ordinary course of nature, to be common mother, it might be inferred that the instincts of the insects would lead them to disembarrass themselves of a sovereign, incapable of discharging the most important functions of her office, and to substitute for her, as we know they always have the power to do, one who should enjoy the plenitude of these functions.

184. Among the innumerable experiments of Huber, those are not least interesting which were directed to this point, that is to say, to submit the faculties of the queen to tests supplied by artificial means, contrived for placing her in social conditions, in which it could scarcely ever happen that she should find herself in the common course of *bee-nature*.

The first question which suggested itself to the great naturalist, was to ascertain whether queens, who thus married so late in life as to have only drone offspring, would exhibit the same spirit of jealous hostility towards the tenants of royal cells, and the future aspirants to thrones, as is invariably manifested by younger royal brides. To determine this it was necessary to place such a queen in a queenless hive, in which, however, there was at least one royal cell tenanted by a princess. Huber, therefore, placed the queen, who had not married until she had bordered upon old maidenhood, in a hive which had no queen, but in which there was one royal cell occupied by a princess. The old bride, whose nuptials had not been celebrated until she had attained the twenty-eighth day of her age, laid nothing of course except drone eggs. On being placed in the hive she exhibited none of the usual signs of hostility against the royal cell. On the contrary, she passed and repassed it many times a day without seeming to take the least notice of it, or to distinguish it in any way from the numerous cells which surrounded it on every side. In such of these latter cells as were unoccupied she deposited eggs, and notwithstanding the jealous guard which the workers kept around

the royal cell occupied by the princess, the queen did not appear either to show a disposition to attack the imprisoned princess, or to fear any attack on the part of the latter.

185. Meanwhile the workers exhibited towards the queen the same respect and homage, lavished upon her the same affectionate cares, offered her honey, and formed round her in the same respectful circle, as they are wont to do round a sovereign possessing all the functions necessary to perpetuate the race.

It appears, therefore, that the postponement of the royal nuptials beyond a certain age, while it deprives the queen of the faculty of having any but male offspring, also deprives her of that instinctive feeling of jealous hostility towards rival queens, which forms a trait so remarkable in the characters of queens, whose nuptials take place at an earlier and more natural age.

To those who regard these little creatures as mere pieces of mechanism, obeying unreflecting impulses, having purposes always directed to the fulfilment of some important end in their economy, it will doubtless be surprising that members of the community so useless as those princesses, who postpone their nuptials until they are incapable of bearing worthier offspring, should not be destroyed as the drones are, after they cease to be useful. So contrary to this, however, is the fact, that no royal bride, however young, is the object of solicitude more tender, affection more sincere, and homage more profound, than those drone-bearing mothers. "I have seen," says Huber, "the workers lavish the most tender care upon such a queen, and, after her decease, surround her inanimate body with the same respect and homage as they had paid to herself while living, and, in the presence of these beloved remains, refuse all attention to young and fertile queens who were offered to them."* It must be admitted that this looks much more like the tenderness of moral affection than the mechanical impression of blind instinct.

186. We have already stated that the royal nuptials are always celebrated in the air, and under the bright beams of the sun, where the bride rises with her numerous suitors, and makes her choice. This bridal excursion into the fields of ether is so intimately interwoven with the customs of these little people, that if, by cutting off her wings before her nuptials, her majesty is deprived of the power of flight, she is consigned irretrievably to a life of single blessedness, since she can never submit to nuptials celebrated in the recesses of the hive, instead of the gay and bright sunshine of the free air.

* It will be observed that, according to the general habit of the blind, Huber uses the language of vision, and describes what he saw with the eyes of Bernens as if he had seen them with his own.

Lest it might be imagined, as indeed Swammerdam supposed, that the marriage is really consummated in this case in the hive, and that her majesty is only rendered sterile by the mutilation she has undergone, Huber cut off the wings of a queen immediately after the royal nuptials, but before her majesty had yet any offspring. In this case, however, her fertility was as great as usual, and she produced the customary number and variety of eggs.

187. One of the questions in insect physiology, which has been attended with a certain degree of doubt, is that which regards the functions of the antennæ. Huber, therefore, desiring to ascertain how the queen would be affected by the privation of these organs, cut off first one and then both, observing the conduct of her majesty after such mutilation.

The excision of one only of the antennæ produced no discoverable effect upon her faculties or conduct, but the amputation of both was followed by some very remarkable consequences.

The antennæ of a queen of limited fertility, who was incapable of having other than drone offspring, were cut off. From the moment she lost these organs she appeared to be affected by a sort of delirious intoxication. She ran over the combs with extraordinary vivacity. She did not give her suite, who formed the usual circle around her, time to make way for her, but rushed madly through them, violently breaking their ranks. She did not deposit her eggs in cells, but dropped them at hazard. The hive not being very full, there were parts of it unoccupied by combs. To these parts she rushed, and remained there a considerable time quiescent, appearing to avoid the presence of her subjects. Some of them, nevertheless, followed her to these deserted places, and eagerly testified their solicitude for her, caressing her, and offering her honey. This she generally declined; and when now and then she seemed disposed reluctantly to accept it, she appeared to lose the power of presenting her proboscis to receive it, directing that organ at one time to the head and at another to the legs of the workers, so that it was only by chance it encountered their mouths. She would then run back to the combs, and from the combs to the glazed sides of the hive, in wild delirium, never ceasing to drop her eggs here and there as she went along.

At other moments she seemed to be tormented with a desire to quit the hive, and rushed to the door for that purpose, but the orifice being too small to allow her body to pass through it, she was forced to desist, and returned to the interior. Notwithstanding this state of delirium, the bees never ceased to lavish upon her those cares which they are accustomed to bestow on their queen; but she received them with indifference.

Whether all this singularity and eccentricity of conduct was to be ascribed to the excision of the antennæ, or to that mutilation combined with the partial sterility which limited her offspring to drones, was not clear. To decide this point, Huber amputated the antennæ of a perfect queen, married at an early age, and who was bearing a numerous offspring, consisting of workers, drones, and princesses. This queen he placed in the same hive with the former, with a view to determine at once two questions, the one relating to the general conduct of the amputated queen, and the other, that which regarded the mutual bearing of two mutilated personages.

The general conduct was the same as that of the former queen. There was the same wild delirium; the same rushing here and there as if under the influence of intoxication; the same efforts to escape from the hive; and, in a word, the same peculiarity of conduct and manners. A like difference was apparent in their conduct towards each other. Instead of entering into deadly combat, as queens in their natural state would have done in like circumstances, they met and passed each other again and again without the slightest indication of mutual hostility. This is perhaps the strongest proof which can be obtained, that the privation of the antennæ utterly subverted their natural instincts.

Another curious social anomaly was manifested on this occasion. It will be recollected that where a strange queen is introduced into a hive over which a regular sovereign already presides, the population surround her, confine her as a prisoner within a ring of sentinels, and refuse to permit her to enter their city. In the present case, no such measures were adopted. On the contrary, the second mutilated queen was received with the same signs of welcome, and immediately became the same object of attention and homage as the first.

But the most wonderful fact of all those developed in this series of experiments, was that when a third queen in the perfect state, without mutilation, was introduced, the bees who had already treated the other two so well, immediately proceeded to maltreat this third and perfect queen. They seized her, dragged her about, bit her, and so closely surrounded her as to leave her room neither to move nor to breathe.

Having observed the apparent desire of these mutilated queens to issue from the hive, which they were only prevented from doing by the limited magnitude of the door, and desiring to see whether the bees or any considerable number of them would depart with her, as they would do with a perfect queen, Huber, after taking away the two queens who were sterile, or partially so, and leaving her who was fruitful in all respects, but deprived

of her antennæ, he enlarged the door so as to allow her free passage through it. So soon as this was done, she went out, and took flight, but not a single bee accompanied her. She was, moreover, so heavy, being full of eggs, that she was not able long to sustain herself on the wing, and fell to the ground.

Various conjectures are made by Huber to explain this singular departure from the prevailing habits of the insect, but none of them appear so satisfactory as to require to be reproduced.

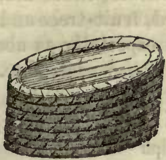


Fig. 85.—Oblique piece to elevate a village hive.

Fig. 86.—The bee-dress.

THE BEE.

CHAPTER VII.

188. Apiculture.—189. Suitable localities and pasturage.—190. The Apiary.—191. Out-door Apiary.—192. Bee-house.—193. Cabinet bee-houses.—194. Form and material of hives.—195. Village hive.—196. English hive.—197. Various forms of hives.—198. Various forms of bee-boxes.—199. Bee-dress and other accessories of apiculture.—200. Purchase of hives.—201. Honey harvest.—202. Honey and wax important articles of commerce.—203. Various sorts of wild honey.—204. Periodical migration of bees.—205. Poisoned honey.—206. Maladies of bees.—207. Curious case of abortive brood.—208. Superstition of bee cultivators.—209. Enemies of bees.—210. Attacks of bees when provoked.—211. Anecdote of Mungo Park.—212. Anecdote of Thorley.—213. Bee wars.—214. Curious case of a battle.

188. Apiculture is the name given to the art by which the products of the industry of the bee are augmented in quantity, improved in quality, and rendered subservient to the uses of man.

189. The most favourable localities for the practice of apiculture are of course those of which the climate is suitable to the habits and character of the insect, and which most abound in those vegetable productions on which it loves to feed. Among these the principal are saintfoin, Dutch clover (*trifolium repens*), buckwheat, rape, honeysuckle, clover (*trifolium pratense*), and yellow trefoil (*medicago lupulina*). According to Dr. Bevan, the earliest

resources of the bee are, however, the *willow*, *hazel*, *osier*, *poplar*, *sycamore*, and *plane;* to which may be added, the *snow-drop*, *crocus*, *white alyssum*, *laurustinus*, *orange* and *lemon trees*, *gooseberry* and *currant* and *raspberry bushes*, *sweet marjoram*, *winter-savory*, *thyme*, and *mint*. In a word, fruit-trees and greenhouse plants and shrubs in general, such especially as abound in ornamental grounds, all constitute a part of bee-pasturage.

> " First the gray willows' glossy pearls they steal,
> Or rob the hazel of its golden meal ;
> While the gay crocus and the violet blue
> Yield to the flexile trunk ambrosial dew.
>
> EVANS, *quoted by* BEVAN.

An undulating country is highly favourable to the bee.

190. The apiary should be near the dwelling-house, in the garden, and in a position sheltered from unfavourable winds. The farm and poultry-yard should be avoided, as well as too great proximity to railways, forges, factories, bakehouses, workshops, and the like. The bee loves tranquil spots, planted with ornamental shrubs and fruit-trees, and sown with sweet flowers, such as mignonette, thyme, mint, rosemary, &c. The aspect of the apiary may be east, west, or south, according as the one or other affords best shelter, but never north.

191. The hives should be placed on separate stands, a few feet apart, should be clear of any wall or fence, and elevated eighteen inches or two feet above the ground.

Hives are sometimes assembled together in the open air, forming an out-door apiary, such as is shown in fig. 54, p.1, in which case they are generally made of straw, and protected in cold weather by straw roofs, but sometimes also formed of wooden boxes, as shown in the figure.

This arrangement, having the advantage of simplicity and cheapness, is most commonly adopted, especially by those to whom economy is important, and in warm climates where shelter is less necessary.

192. Under other circumstances bee-houses are much more strongly recommended, as well for comfort and convenience as for security. The bee-house, one form of which is shown in fig. 55, p. 33, consists of two or more rows of shelves, established one above the other, on which the hives are placed at distances of from twelve to eighteen inches apart, so that the bee-doors shall be from two to three feet asunder. The house should be thatched not only on the roof but on the sides and ends. A passage should be provided for approaching the hives behind, and windows in the side for ventilation.

193. A form called the Cabinet bee-house is shown in fig. 56,

p. 65, where B B are doors, one of which is glazed, and A a pipe of tin or caoutchouc, by which the bees have ingress and egress.

194. Hives have been constructed of different materials, as straw, osiers, rushes, sedges, wood, and earthenware; and of still more various forms, some being bell-shaped or conical, some cylindrical, some square in their section, some with rectangular and some with oblique tops, being internally divided by comb-frames fixed or movable, by shelves, and other expedients.

Their forms of structure depend in some degree upon the object of the proprietors. When apiculture is prosecuted on a large scale for the produce of honey and wax, as articles of trade, the foreign cultivators prefer hives of the most simple forms and most easy construction, and those from which the products can be obtained with most facility. The material preferred is, generally, straw or rushes. The process of making such a hive is indicated in fig. 57.

Fig. 57.—Process of making a straw hive.

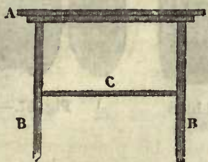


Fig. 61.—Movable comb-frame of the village hive.

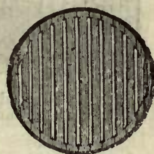


Fig. 59.—Top of the cylindrical body of the village hive.

195. The bell-shaped straw hive, called the village hive, represented on the right of fig. 58, p. 49, is cylindrical in the body, and surmounted by a bell-shaped cap. The top of the cylindrical body is covered by a frame of bars, shown separately in fig. 59, and the cap itself is shown in fig. 60.

Fig. 60.—Cap of the village hive.

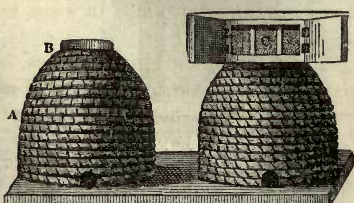


Fig. 62.—Dewhurst's hive.

One of the movable comb-frames is shown in fig. 61, where A is the vertical section of the stage, shown by plan in fig. 59; B the uprights, and C a shelf shown in vertical section.

196. The English hive of Dewhurst, having a box at the top, is shown in fig. 62; where A is the body of the hive, B the opening at the top, and C the box provided with shutters.

197. In fig. 63, p. 81, is shown a form of straw hive used in Scotland, and in fig. 64 the Radouan hive, similar in form to the village hive, but provided with movable pieces, by placing which successively below it, its elevation can be gradually augmented without disturbing the superior part, so as to give increased space to the bees and prevent the issue of swarms.

A form of hive much used in the South of France, and known to French apiarists as the Vulgar Hive (Ruche Vulgaire), is shown on the left of fig. 58, p. 49, in the process of transferring the bees from one hive to another.

A form of cork hive used in the South of France is shown in

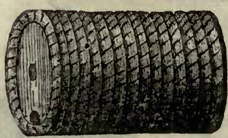


Fig. 66.—Cylindrical hive (Switzerland and Italy).

Fig. 67.—Della Rocca hive (Greece and Turkey).

fig. 65; and a cylindrical hive with its axis horizontal, much

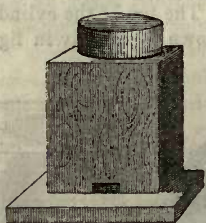


Fig. 68.—Murie's bee-box, with cylindrical cap (French).

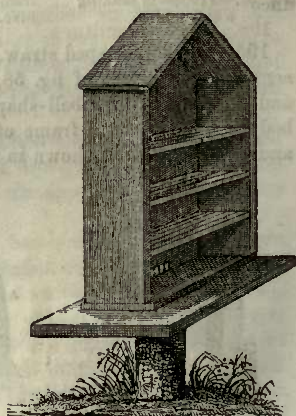


Fig. 69.—De Frarière's garden hive.

used in Switzerland and Italy, is shown in fig. 66.

In Greece and Turkey a hive of earthenware, known as that of della Rocca, is much used, fig. 67.

Straw hives have the advantage over wooden boxes in being better non-conductors of heat, and therefore preventing immoderate cold in winter and immoderate heat in summer in the

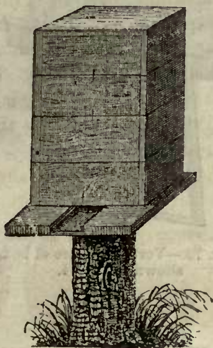


Fig. 70.—Patteau's bee-box, with horizontal divisions.

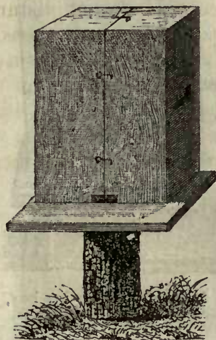


Fig. 71.—Gélieu's bee-box, with vertical division.

interior. They are on this account preferred where the apiary is uncovered.

198. When apiculture is practised partly for the purpose of

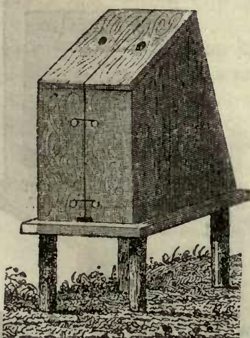


Fig. 72.—Feburier's bee-box, with vertical division and sloping roof.

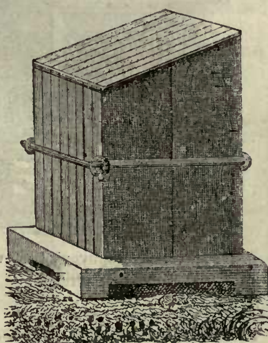


Fig. 73.—Huber's experimental leaf-hive.

observing the habits of the insect, boxes with divisions and

movable comb-frames, with glazed openings and other like contrivances, are used. These *bee-boxes*, as they are called, are

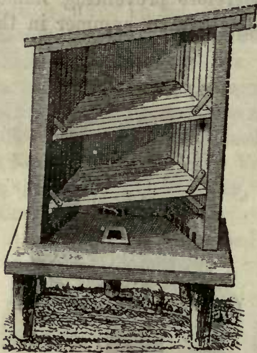


Fig. 74.—Debeauvoy's bee-box, with sloping roof and shelves.

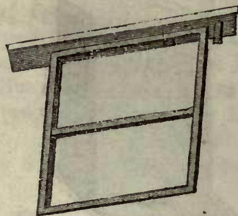


Fig. 75.—Vertical frame of box shown in fig. 74.

infinitely various in form, and although our limits will not allow us to enter into the details of the advantages derived from them

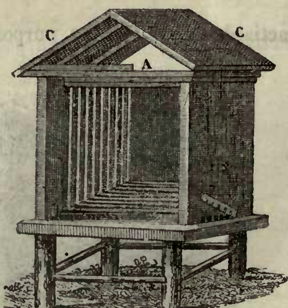


Fig. 77.—Debeauvoy's box, with vertical frames.

Fig. 78.—Shutter of box shown in fig. 77.

by their inventors and contrivers, it will nevertheless be useful to show the forms of those most generally used.

The common bee-box used in the South of France is shown in fig. 76, p. 17, the cover C being hinged, so as to be capable of being raised at pleasure. The process of transferring the bees

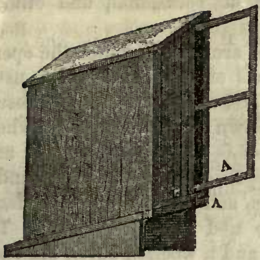


Fig. 78.*—Lefebvre's box, with movable frames. A, a frame drawn out.

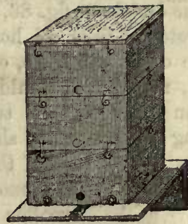


Fig. 79.—Hamet's bee-box, with oblique horizontal divisions.

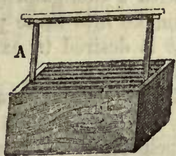


Fig. 80.—One of the divisions by which fig. 79 is elevated, with a movable frame, A, drawn out.

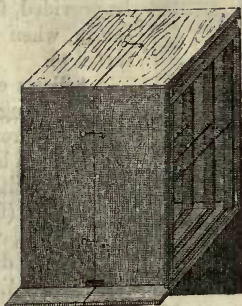


Fig. 81.—Hamet's bee-box, with divisions and movable frames.

from one hive to another by smoking them, is indicated, and also the method of hiving a swarm.

Fig. 82.—Uprights of fig. 81.

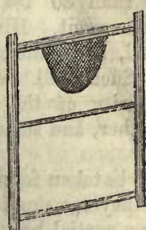


Fig. 83.—Frame of fig. 81.

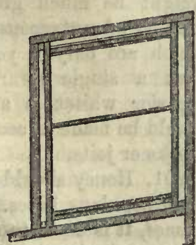


Fig. 84.—Side of fig. 81, with its movable frame.

199. In the practical details of apiculture there are many

accessories, some of which are of occasional, and others of constant use.

The *bee-dress*, fig. 86, is a sort of armour, by which the operator is protected from all hostile attacks of the insect. It is usually made of Scotch gauze, or catgut, and so formed as to inclose the head, neck, and shoulders, as shown in fig. 76, p. 17, where a person invested with such a dress is represented in the act of hiving a swarm. It should have long sleeves to tie round the wrists over a pair of thick gloves, and the body should descend low enough to be tied round the waist. Thick woollen stockings and a woollen apron are recommended, the material being one from which the bee can readily withdraw its sting.

Fig. 87.

Fig. 88.

Knives of different forms (figs. 87, 88) should be provided, for the partial removal of the honey-combs, when the smothering process is not resorted to.

A bellows connected with a fumigator (fig. 89) for projecting tobacco-smoke into those parts of the combs from which it is desired to expel the bees, should be provided.

A hive with a handle for mixing swarms is often useful (fig. 90).

A basket, with an open bottom, placed over a tub for the purpose of draining the honey-combs, is also a convenient accessory (fig. 91).

200. A hive should, in general, be purchased in autumn, and its value will be pretty well ascertained by its weight. That of a good hive which will be sure to go through the winter, and to be productive in the ensuing season, should be from 25 to 30 lbs., and should contain about a peck of bees. If the weight be much greater than 30 lbs., a part of the honey may be advantageously taken out. Hives are to be preferred which are only a year old, and which have sent out no more than a single swarm. Such will be distinguished by the superior whiteness and purity of the combs. The transport should be made in cool weather, and should be conducted without shocks or jolts.

201. Honey should never be taken from any but the nearest and most populous hives. If they are provided with movable comb-frames, it is usual to make a partial harvest in May, the principal stores of the insect being collected between the middle of May and the end of June, the commencement and termination, however, varying three or four weeks, according to the climate peculiar to the locality.

Dr. Bevan recommends, as a general rule, that no honey should be taken from a colony the first year of its being planted.

Fig. 89.

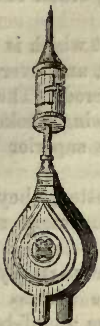


Fig. 90.

Fig. 91.

To make a partial collection of honey, the hive is opened at the top or at the side, and the bees expelled from the combs by puffing tobacco-smoke upon them. The combs are then cut away with knives of suitable forms (figs. 87, 88). This operation requires to be performed with skill and care, so as to avoid as much as possible irritating the bees. To withdraw the queen from the part of the combs which are to be removed, the operator taps with his fingers on the opposite part of the hive, which will cause her majesty to run there, to ascertain the cause of the noise. If any bees are seen upon the combs removed, they may be brushed off with a feather, when they will generally return to the hive. The combs taken away are replaced either by empty ones, or by full combs taken from the lower part of the hive.

When hives are constructed on the principle of those shown in fig. 64, &c., consisting of several parts separable, laid one upon the other, the honey may be collected by causing the bees to desert the division intended to be removed by tapping on remote parts of the hive, and by projecting tobacco-smoke on them.

These operations may be performed in the day between ten and three o'clock. If the country be one rich in bee pasturage, a superior division of the hive may be taken away and replaced by an empty one, if the operation take place early in the season; and this latter may sometimes be again harvested before the close of the season, so as to obtain honey of the purest and finest quality.

But where the pasturage is not so rich, or where the operation is performed later in the season, it will be necessary either not to replace the division harvested, or to put the empty division at the bottom of the hive.

To collect the honey in the hives of the form represented in fig. 58, p. 49, called the vulgar hive, it is necessary either to expel the bees or to smother them.

To expel and transfer them to another hive, that which is to be harvested is inverted, as shown in fig. 58, p. 49, and over it is placed the hive to which the bees are to be transferred. The bees may be driven from one to the other, either by being smoked, as shown in fig. 76, p. 17, or by tapping upon the superior hive, fig. 58, p. 49.

If some bees remain in the hive to be harvested, they will voluntarily pass into the new hive by the arrangement represented in fig. 76, p. 17.

When the hive is harvested, either wholly or partially, by affecting the bees with temporary asphyxia, the process is as follows: after having beaten the black powder from a puff-ball of Lycoperdon, it is placed with some red charcoal in the fumigator, fig. 89, the nozzle of which is inserted at the door of the hive. The bellows being worked for five or six minutes, the bees will fall insensible from the hive, when the combs may be removed, wholly or partially, as the case may be. In twenty or thirty minutes the bees will revive, and re-enter the hive, or may be received in a new one if desired.

If it be not desired to preserve the bees, the hive may be placed over a pit into which they will fall, and where they may be buried.

To obtain honey of the first quality, the purest combs, containing neither bee-bread nor brood, being selected, are drained through a hair-sieve or osier-basket. Their product, called virgin honey, is limpid. It hardens and keeps if potted and put in a cool and dry place. Honey of inferior quality is obtained by pressing the residue of the combs, and exposing them to heat.

Whenever honey is collected, wax may also be obtained, but the latter substance may be separately collected at the close of the winter, by paring away the lower ranges of comb, taking away by the knife those which are old, black, and mouldy, and those which have been attacked by the moth. The wax is dissolved with boiling water, after which it is purified and collected in moulds of glazed pottery.

202. Honey and wax, the products of bee industry, form important articles of commerce in various parts of the world.

Although the production of wax is not confined to the bee,

nearly all of that article employed in Europe is of bee manufacture.

Although honey has lost much of its importance as an article of food, since the discovery and improvement of the fabrication of sugar, it is still regarded as a luxury, and of considerable value in this country, as the material out of which a wholesome vinous beverage is produced. In many inland parts of the continent where sugar is costly, few articles of rural economy could be less spared. In the Ukraine some of the peasants possess from 400 to 500 hives, and are said to make more profit of their bees than even of their corn. In Spain the nurture of bees is carried to a still greater extent; according to Mills, a single parish priest was known to possess the almost incredible number of 5000 hives.

The common hive-bee is the same, according to Latreille, in every part of Europe, except in some districts of Italy, where a species called the Apis ligustica of Spinola is kept. This species is also said to be cultivated in the Morea and the Ionian Isles. Honey, however, is also obtained from many other species of bees, as well wild as domesticated.

203. The rock honey of some parts of America, which is very thin and as clear as water, is the produce of wild bees, which suspend their clusters of thirty or forty waxen cells, resembling a bunch of grapes, from a rock. In South America large quantities of honey are collected from nests built in trees by the Trigona Amalthea and other species of this genus, under which, according to Kirby, should be included the Bamburos, to gather the honey of which the whole population in Ceylon make excursions into the woods.

According to Agara, one of the chief articles of food of the Paraguay Indians is wild honey.

Captain Green observes, that in the Island of Bourbon, where he was stationed for some time, there is a bee which produces honey much esteemed there, of a green colour, having the consistency of oil, and which, besides the usual sweetness of honey, has a remarkable fragrance. This green honey is exported to India in considerable quantities, where it bears a high price.

A species of bee called the Apis fasciata was probably cultivated ages before the present hive-bee was attended to. This species is still so extensively cultivated in Egypt that Niebuhr met on the hill between Cairo and Damietta a convoy of 4000 hives, which the apiarists of that country were transporting from a region where the season had passed, to one where the spring was later.

204. This periodical migration of bees is by no means of modern date. According to Columella, the Greeks used to send their

bee-hives at certain seasons of the year from Achaia into Attica, and a similar custom still prevails in Italy, and even in this country in the neighbourhood of heaths.

Among the domesticated species of bees may be also mentioned the Apis unicolor in Madagascar, the Apis Indica at Pondicherry and in Bengal, and the Apis Adansonii at Senegal.

Fabricius affirmed that the Apis Acraensis laboriosa, and others in the East and West Indies, might be domesticated with greater advantage than even the common hive-bee of Europe, called the Apis mellifica.

205. Honey is one of the class of aliments which requires to be used with some precaution, since not only are certain constitutions of body affected injuriously by it, even in its most natural and wholesome state, but it happens occasionally that the insects which collect it resort to poisonous flowers, which impart their noxious properties to the honey extracted from them.

Kirby mentions the case of a lady of his acquaintance upon whom ordinary honey acted like poison, and says, that he heard of instances in which death ensued from eating it.

But where the bee unfortunately resorts to poisonous plants, the consequences are not thus limited to individuals of peculiar idiosyncrasies. Dr. Barton has given a remarkable example of this.*

In the autumn and winter of the year 1790, an extensive mortality was produced amongst those who had partaken of the honey, collected in the neighbourhood of Philadelphia. The attention of the American government was excited by the general distress; a minute enquiry into the cause of the mortality ensued, and it was satisfactorily ascertained that the honey had been chiefly extracted from the flowers of *Kalmia latifolia*. Though the honey mentioned in Xenophon's well-known account of the effect of a particular sort, eaten by the Grecian soldiers during the celebrated retreat, after the death of the younger Cyrus, did not operate fatally, it gave those of the soldiers who ate it in small quantities the appearance of being intoxicated, and such as partook of it freely, of being mad or about to die, numbers lying on the ground as if after a defeat. A specimen of this honey, which still retains its deleterious properties, was sent to the Zoological Society in 1834 from Trebizond, on the Black Sea, by Keith E. Abbott, Esq.

206. The maladies of the bee proceed from three causes,—hunger, damp, and infection; all of which admit of prevention when the insect is maintained artificially.

* American Philosophical Transactions, vol. v. of the year 1790.

Dysentery is the malady which is at once the most dreaded by bee-owner, and the most easy to be prevented. It is always due to damp or to bad diet, such as impure honey and indigestible syrups. The remedies are consequently to place the hives in a dry situation, and to supply the insects with wholesome food, such as good honey mixed with a little generous wine. The greatest care should also be taken to remove such combs as may be rendered foul by excrement, and to clean the shelves in the bee-houses.

Among other maladies may be mentioned, diseases of the antennæ, vertigo, and abortive broods of eggs. These are generally produced by bad food, damp, and drafts of cold air. On that account some bee-cultivators reject the forms of hive or bee-houses having two doors on opposite sides, thus placed for the purpose of ventilation. This arrangement is never seen in the natural habitations of the insect.

207. Dr. Bevan mentions a case of abortive brood which occurred in one of Mr. Dunbar's hives. The colony had been very strong in the previous autumn, and possessed a fertile queen, but in the spring it failed, and did not swarm. On examination, he found the four central leaves of the hive (which was one of Huber's, fig. 73), full of abortive brood, by the presence of which the queen seemed to be paralysed, though she still laid a few eggs at the edge of the combs. As the population seemed gradually diminishing, Mr. Dunbar cut out the whole of the abortive brood, removed the old queen, and added an after swarm to the family. The conjoined bees soon betook themselves to work, replaced the old combs by new ones, and laid in an ample store of honey. This is an operation called *castration* by French apiculturists; and in all such cases it is prudent, in order to prevent contagion, to have the infected combs burnt or buried.

208. Butler, in his "Female Monarchy," relates a story of a credulous lady who devoted herself to the cultivation of bees. This person having gone to receive the sacrament, retained the consecrated wafer; and at the suggestion of a friend, more simple than herself, placed it in one of her diseased hives. The bee plague, according to her report, immediately ceased; honey accumulated; and, on examining the inside of the hive, she found there, to her astonishment and admiration, a waxen chapel, of wondrous architecture, supplied with an altar, and even with a steeple, and a set of bells, all constructed of the same material.

209. The most dangerous enemies of the bees are the larvæ of certain moths, which when once they take possession of a hive cannot be extirpated, and no remedy remains but to transport the entire population of the insect colony to a new habitation.

The bee-louse, an insect about the size of a flea, often infests populous hives, so as greatly to annoy the bees by fixing itself upon them. Sometimes two or more attach themselves to a single bee, making it restless and indisposed for its usual industry.

A magnified view of one of these parasites is shown in fig. 92, as seen from above; and in fig. 93, as seen from below.

Fig. 92.—Bee Louse, seen from above.

Fig. 93.—Bee-Louse, seen from below.

That universal plunderer the wasp, and his formidable congener the hornet, often seize and devour them; sometimes ripping open their body to come at the honey, and at others carrying off that part in which it is situated. Wasps frequently take possession of a hive, having either destroyed or driven away its inhabitants, and consume all the honey it contains. Nay, there are certain idlers of their own species, called by apiarists, corsair bees, which plunder the hives of the industrious.

210. Examples have been already cited, in which bees have manifested peculiar personal antipathies, which have been ascribed, in the cases mentioned, to some odour, offensive to the insect, proceeding from the obnoxious individuals. Independently, however, of such general causes of hostility, the insects are sometimes provoked against even their best friends and most familiar acquaintances, by occasional circumstances. Kirby relates, that although he was generally exempt from their hostility, he could not venture with impunity to put them out of humour. Thus happening one day, during the season when asparagus was in blossom, to pass among the beds, which were crowded with bees, he discomposed them so much that he was obliged to make a hasty retreat, pursued by a swarm of his offended friends.

211. In Mungo Park's last mission to Africa, he was much annoyed by bees. His people, searching for honey, having disturbed a large colony of them, the insects sallied forth by myriads, and attacking men and beasts indiscriminately, put them all to the rout. One horse and six asses were killed or missing in consequence of their attack, and for half an hour the bees seem to have completely put an end to their journey. Isaacs, upon

another occasion, lost one of his asses, and one of his men was almost killed by them.*

212. Bees, however, as we have already observed, are not usually ill-tempered; and, if not molested, are generally inoffensive. Thorley relates,† that a maid servant, who assisted him in hiving a swarm, being rather afraid, put a linen cloth as a defence over her head and shoulders. When the bees were shaken from the tree on which they had alighted, the queen probably settled upon this cloth, for the whole swarm covered it, and then getting under it, spread themselves over her face, neck, and bosom, so that when the cloth was removed, she was quite a spectacle. She was with great difficulty kept from running off with all the bees upon her. But at length her master quieted her fears, and began to search for the queen. He succeeded, and expected that when he put her into the hive the bees would follow. He was, however, in the first instance disappointed, for they did not stir. Upon examining the cluster again, he found a second queen, or probably the former one, which had flown back to the swarm. Having seized her, he placed her in the hive, and kept her there. The bees soon missed her, and crowded into the hive after her, so that, in two or three minutes, not one remained on the poor frightened girl. After this escape she became quite a heroine, and would undertake the most hazardous employment about the hives.

213. The duels of rival queens have been already mentioned. Similar combats take place occasionally between the workers of one hive and those of another. Nor are such wars confined to single combats. General actions take place now and then between neighbouring colonies. This occurs when one takes a fancy to a hive which another has pre-occupied. Reaumur witnessed one of these battles, which lasted a whole afternoon, and in which great numbers fell on the one side and the other. In such cases, each combatant selects his opponent, and the victorious one flies away with the slain body of its enemy between its legs. After making a short flight thus, she deposits it on the ground, and rests near it, standing on her four anterior legs, and rubbing the two hinder legs against each other, as though she enjoyed the sight of her victim.

214. The following account of a bee battle was published in a Carlisle newspaper. A swarm of bees flying over a garden, where a newly tenanted hive was placed, suddenly stopped in their flight, and, descending, settled upon the hive, completely covering it. In a little time, they began to make their way to the door, and poured into it in such numbers, that it became completely

* Park's Last Mission, 153, 297. † Thorley, 150.

filled. A loud humming noise was heard, and the work of destruction immediately ensued. The winged combatants sallied forth from the hive until it became entirely emptied, and a ferocious battle commenced in the air between the besiegers and the besieged. These intrepid warriors were so numerous, that they literally darkened the sky overhead like a cloud. Meanwhile, the destructive battle raged with great fury on both sides, and the ground beneath was covered with the killed and wounded. Hundreds were seen dispersed on the ground, lying dead, or crawling about in a disabled state. To one party at length the palm of victory was awarded, and they settled upon a branch of an adjoining tree, from which they were removed to the deserted hive, of which they took quiet possession, and commenced and continued their usual industry.

STEAM NAVIGATION.

CHAPTER I.

1. Inventors of steam navigation uneducated.—2. First steamers on the Hudson and the Clyde.—3. Sea-going steamers due to British engineers.—4. Progress of steam navigation from 1812 to 1837.—5. Atlantic steamers projected.—6. Abstract possibility of the voyage could not be doubted.—7. The voyage had been already made by two steamers.—8. Projects advanced in 1836.—9. Discussion at Bristol in 1837.—10. Report of Dr. Lardner's speech in the *Times* of 27th August, showing the falsehood of the report that he pronounced the project impracticable.—11. Atlantic steam voyage advocated by Dr. Lardner in 1836-7.—12. The practical results of the various projects prove the truth of his predictions.—13. The Cunard steamers, established on the conditions suggested by him, were alone successful.—14. Voyages of these steamers.—15. Other lines established.—16. Probable extension of steam navigation to the general purposes of commerce.—17. Auxiliary steam-power the most probable means of accomplishing this.—18. Advantages of subaqueous propulsion.—19. Means of realising them.—20. Improved adaptation of steam-power to vessels of war required.—21. Mercantile steam-marine available for national defence.—22. Principle of marine-engine.—23. Propellers.—24. Paddle-wheels and screws.—25. Arrangement of paddle-wheels.—26. Paddle-shaft.—27. General arrangement of marine-engine.

1. If the spirits of Watt, Trevithick, and Fulton can look down on the things of this nether world, and behold the grand results their discoveries and inventions have produced, what triumph must be theirs! For half a century the steam-engine had remained a barren fact in the archives of science, when the self-taught genius of the Glasgow mechanic breathed into it the spirit of vitality, and conferred upon it energies by which it revived the drooping commerce of his country, and, when the auspicious epoch of general peace arrived, diffused its beneficial influence to the very skirts of civilisation. Scarcely had the fruit of the labour of Watt ripened, and this great mover been adopted as the principal power in the arts and manufactures, than its uses received that prodigious extension which resulted from its acquiring the LOCOMOTIVE character. As it had previously displaced animal power in the MILL, and usurped its nomenclature, so it now menaced its displacement on the ROAD. A few years more witnessed perhaps the greatest and most important of all the manifold agencies of steam—that by which it has given wings to the ship, and bade it laugh to scorn the opposing elements, transporting it in triumph over the expanse of the trackless ocean, regardless of wind or current, and conferring upon locomotion over the deep a regularity, certainty, and precision, surpassed by nothing save the movement of chronometers or the course of the heavenly bodies. Such are the vast results which have sprung from the intelligence of men, none of whom shared those privileges of mental culture enjoyed by the favoured sons of wealth; none of whom grew up within the walls of schools or colleges, drawing inspiration from the fountains of ancient learning; none of whom were spurred on by those irresistible incentives to genius arising from the competition of ardent and youthful minds, and from the prospect of scholastic honours and professional advancement. Sustained by that innate consciousness of power, stimulated by that irrepressible force of will, so eminently characteristic of, and inseparable from, minds of the first order, they, in their humble and obscure positions persevered against adverse and embarrassing circumstances, impelled by the faith that was in them, against the doubts, the opposition, and, not unfrequently, the ridicule of an incredulous world, until at length, by time and patience, truth was triumphant, and mankind now gathers the rich harvest sown by these illustrious labourers.

2. It was about the eighth year of the present century that Fulton launched the first steamboat on the Hudson. After the lapse of four years the first European steamboat was established on the Clyde. From that time the art of steam-navigation, in the two great maritime and commercial nations, advanced with a

steady and rapid progress. But it took different directions, governed by the peculiar geographical and commercial circumstances attending these countries. The genius and enterprise of the United States saw before and around it a vast territory, intersected by navigable rivers of unequalled length, forming lines of water communication on a colossal scale between its extensive interior and the sea-board. The Mississippi and its tributaries, with their sources, lost in distant tracts as yet untrodden by civilised man, and navigable by large vessels for many thousands of miles,—the Hudson, all but touching upon those magnificent inland seas that stretch along the northern boundary, and are almost connected with the Mississippi by the noble stream of the Illinois,—the Delaware, the vast Potomac, and, in fine, a coast thousands of miles in extent, fringed by innumerable bays and harbours, and land-locked basins having all the attributes of lakes,—these addressed themselves to the eye of the engineer and the capitalist, and determined the direction of enterprise. The application of steam power to inland navigation—the construction of vessels suited to traverse with speed, safety, and economy, rivers and lakes, harbours, bays, and extensive inlets—this was the task and the vocation of the American engineer, and this the interest of the capitalist and the merchant.*

3. The problem of steam-navigation, however, presented itself to the British engineer under other conditions. In a group of islands intersected by no considerable navigable rivers, and neither requiring nor admitting any inland navigation save that of artificial canals,—separated, however, from each other and from the adjacent continent of Europe by straits, channels, gulfs, and other arms of the sea,—it was apparent that if steam power should become available at all, it must be adapted to the navigation of these seas and channels—it must be adapted to accelerate and cheapen the intercourse between the British islands, between port and port upon their coasts, between them and the various ports on the adjacent coast of Europe, and finally to establish a communication with the Mediterranean and the coasts of Africa, Asia, and Europe, which are washed by it. While the American, therefore, was called on to contrive a steam-vessel adapted to inland and smooth-water navigation, the British engineer had the more difficult task, to construct one which should be capable of meeting and surmounting all the obstructions arising from the vicissitudes of the deep.

The result of the labour and enterprise of the English nation, directed to this inquiry, has been the present sea-going steam-ship.

* For a more developed notice of American Steam Navigation, see Railway Economy, chap. xvi., and Museum, vol. ii. p. 17.

4. In the quarter of a century which elapsed between 1812 and 1837 steam-navigation made a steady and continuous, but not a sudden progress. The first lines of steamers were established naturally between the ports of England and the nearest sea-ports of Ireland on the one side, and France on the other. The length of each unbroken passage was then regarded as the great difficulty of the project. Thus steamers were established between Holyhead and Dublin, and between Dover and Calais, long before projectors ventured to try them between Dublin and Liverpool, or between London and the Low Countries.

After some years' experience, however, and the consequent improvement of the marine engine, passages of greater length were attempted with success. Lines of steamers were established first between more distant parts of the United Kingdom; as, for example, between London and Edinburgh, and between Dublin, Liverpool, and Glasgow. At a later period still longer trips became practicable, and lines of steamers were established between the United Kingdom and the Mediterranean; touching, however, for fuel at the peninsular ports, such as Corunna, Lisbon, and Gibraltar.

During this period, also, a fleet of steamers was constructed by government for post-office purposes, and a steam navy was gradually created, among which were found ships of large tonnage and considerable power.

5. At length, in the year 1836, a project, then considered as a startling one, was first announced, to supersede the far-famed New York and Liverpool packet-ships, by a magnificent establishment of STEAM-SHIPS.

These vessels were to sustain a constant, regular, and rapid communication between the New and Old World. They were to be the great channel for commerce, intelligence, and social intercourse, between the metropolis of the West and the vast marts of the United Kingdom; they were, in a word, to fulfil, not only all the functions which for half a century had been so admirably discharged by the packet-ships, but to do so with expedition increased in a threefold proportion at the least. Such an announcement could not fail to captivate the public. The results to be anticipated were so obvious, so grand, and must be attended with effects so widely spread, that all persons of every civilised nation at once felt and acknowledged their importance. The announcement of the project was accordingly hailed with one general shout of acclamation.

Some, who, being conversant with the actual condition of the art of steam-engineering as applied to navigation, and aware of various commercial conditions which must affect the problem, and

were enabled to estimate calmly and dispassionately the difficulties and drawbacks, as well as the advantages, of the undertaking, entertained doubts which clouded the brightness of their hopes, and warned the commercial word against the indulgence of too sanguine anticipations, of the immediate and unqualified realisation of the project. They counselled caution and reserve against an improvident investment of extensive capital, in schemes which could still be only regarded as experimental, and which might prove its grave. But the voice of remonstrance was drowned amid the enthusiasm excited, by the promise of an immediate practical realisation of a scheme so grand. The keel of the Great Western was laid; an assurance was given that the seasons would not twice run through their changes, before she would be followed by a splendid line of vessels, which should consign the packet-ships to the care of the historian as "things that were."

6. It cannot be seriously imagined, that any one who had been conversant with the past history of steam-navigation, could entertain the least doubt of the abstract practicability of a steam-vessel making the voyage between Bristol and New York.

A vessel having as her cargo a couple of hundred tons of coals would, *cæteris paribus*, be as capable of crossing the Atlantic as a vessel transporting the same weight of any other cargo. A steam-vessel of the usual form and construction would, it is true, labour under comparative disadvantages, owing to obstructions presented by her paddle-wheels and paddle-boxes; but still it would have been preposterous to suppose that these impediments could have rendered her passage to New York impracticable.

7. But, independently of these considerations, it was a well-known fact, that, long antecedent to the epoch now adverted to, the Atlantic had actually been crossed by the steamers Savannah and Curaçoa. Nevertheless a statement was not only widely circulated, but generally credited, that I had publicly asserted that a steam voyage across the Atlantic was "*a physical impossibility!*"

Although this erroneous statement has been again and again publicly contradicted through various organs of the press, it continues nevertheless to be repeated. I shall therefore take this opportunity once more to put on record, what I really did state on the occasion, on which I am reported to have affirmed that the Atlantic steam voyage was a physical impossibility.

8. Projects had been started in the year 1836 by two different and opposing interests, one advocating the establishment of a line of steamers to ply between the west coast of Ireland and Boston, touching at Halifax; and the other a direct line, making an uninterrupted trip between Bristol and New York. In the year

1836, on the occasion of the meeting of the British Association in Dublin, I had advocated the former of these projects.

9. On the occasion of the next meeting in 1837 at Bristol, I again urged its advantages, and by comparison discouraged the project of a direct line between Bristol and New York. When I say that I advocated one of these projects, it is needless to add that the popular rumour, that I had pronounced the Atlantic voyage impracticable, is utterly destitute of foundation. But I am enabled to offer more conclusive proofs than this, that, so far from asserting that the Atlantic voyage by steam was impossible, *I distinctly affirmed the contrary.*

The *Times* newspaper sent a special reporter to attend the meeting at Bristol, and more particularly to transmit a report of the expected discussion on the Atlantic steam voyage, which at the moment excited much interest.

10. The meeting took place on the 25th, and the report appeared in the *Times* of the 27th of August. From that report I extract the following;—

"Dr. Lardner said he would beg of any one, and more especially of those who had a direct interest in the inquiry, to dismiss from their minds all previously-formed judgments about it, *and more especially upon this question, to be guarded against the conclusions of mere theory*, for if ever there was one point in practice of a commercial nature which, more than another, required to be founded on experience, it was this one of extending steam-navigation to voyages of extraordinary length. He was aware that since the question had arisen, it had been stated that his own opinion was averse to it. *This statement was totally wrong*, but he did feel that great caution should be used in the adoption of the means of carrying the project into effect. Almost all depended on the first attempt, for a failure would much retard the ultimate consummation of the project.

"Mr. Scott Russell said that he had listened with great delight to the lucid and logical observations they had just heard. He would add one word. Let them try this experiment, with a view only to the enterprise itself, but on no account try any new boiler or other experiment, but to have a combination of the most approved plans that had yet been adopted.

"After some observations from Messrs. Brunel and Field, Dr. Lardner, in reply, said, that *he considered the voyage practicable*, but he wished to point out that which would *remove the possibility of a doubt*, because if the first attempt failed it would cast a damp upon the enterprise, and prevent a repetition of the attempt."

Such was the report of the *Times* of the speech in which I was afterwards, and have ever since been, represented as having declared a steam voyage across the Atlantic a *mechanical impossibility!* *

11. What I did affirm and maintain in 1836-7 was, that the long sea voyages by steam which were contemplated, could not at that time be maintained with that regularity and certainty which are indispensable to commercial success, by any revenue which could be expected from traffic alone, and that, without a government subsidy of a considerable amount, such lines of steamers, although they might be started, could not be permanently maintained.

12. Now let us see what has been the practical result.

Eight steam-ships, including the Great Western, were, soon after the epoch of these debates, placed upon the projected line between England and New York; the Sirius, the Royal William, the Great Liverpool, the United States,† the British Queen, the President, the Great Western, and the Great Britain.

The Sirius was almost immediately withdrawn; the Royal William, after a couple of voyages, shared the same fate; the Great Liverpool, in a single season, involved her proprietors in a loss of 6000*l.*, and they were glad to remove her to the Mediterranean station. The proprietors of the British Queen, after sustaining a loss which is estimated at little less than 100000*l.*, sold that ship to the Belgian government. The United States was soon transferred, like the Great Liverpool, to the Mediterranean trade. The President was lost. The Great Western, as is well known, after continuing for some time to make the voyage in the summer months, being laid by during the winter, and after involving her proprietors in a loss of unknown and unacknowledged amount, was sold. Of the Great Britain, the fate is well known.

Thus, it appears, in fine, that after the lapse of nearly fourteen years, notwithstanding the great improvements which took place in steam navigation, the project advanced at Bristol, and there pronounced by me to be commercially impracticable, signally failed.

13. Meanwhile another project, based upon the conditions which I had indicated as essential to the permanence and success of the enterprise, was started.

Mr. Samuel Cunard, a Canadian, who had extensive experience

* Notices of this speech, substantially the same, appeared in the Edinburgh Review, the Monthly Chronicle, and other periodicals of that date.

† This vessel was not actually placed on the line, but was prepared for it. She was afterwards called the Oriental.

in maritime affairs, being associated with some large capitalists who had confidence in his sagacity and skill, laid before the British government a project for a line of Post-office steamers, to ply between Liverpool and Boston, touching at Halifax. But Mr. Cunard insisted strongly on the necessity of providing a considerable fleet of steamers, to ensure that permanence and regularity which were indispensable to the success of the project. He demonstrated that the magnitude of the capital it must involve, and the vast expenditure attending its maintenance, were such as could not be covered by any commercial returns to be expected from it, and that, consequently, it could only be sustained by a liberal subsidy to be furnished by the government. After much negotiation, it was agreed to grant him an annual subsidy of 60000*l.*, upon which condition the enterprise was commenced. Mr. Cunard, however, had hardly embarked in it, before it became evident that this grant was insufficient, and it was soon increased to 100000*l.* per annum. Further experience proved that even this was insufficient to enable Cunard and his associates to maintain the communication in a satisfactory and efficient manner, and the annual subvention was in fine raised to its present amount, that is to say, 145000*l.* sterling per annum.

14. Thus supported, the communication was in 1851 maintained throughout the year. During the four winter months, December, January, February, and March, there were two departures per month from each side, and during the eight other months of the year there was a departure once a week, making a total of forty-four departures from each side, or forty-four voyages going and returning.

These voyages make a total distance sailed of 272800 geographical miles within the year. The subsidy, therefore, amounts to ten shillings and eightpence per mile sailed.

Since the epoch here referred to, steam-navigation has, as is well known, undergone great improvements, and its powers have been proportionally extended. The arrangements of this and other lines of ocean navigation have accordingly undergone, and continue to undergo, modifications having the effect of increasing the frequency and extending the lengths of the trips.

15. Soon after the Cunard line of steamers commenced operations, it was proposed to establish, with government support, a transatlantic line of steamers communicating between Great Britain and its West India colonies. Ultimately the present West India Steam-Packet Company was established, and obtained from the government a subvention greater still in amount than had been granted to the Cunard Company. The amount of this annual grant was 240000*l.*

16. Great as the progress of steam-navigation has been within the last quarter of a century, much still remains to be accomplished, before that vast agent of transport can be regarded as having been pushed to the limit of its powers. Its superior speed, regularity, and certainty, comparatively with sailing-vessels, have naturally first attracted to it passengers, despatches, and certain descriptions of merchandise to which expedition is important, and which can bear a high rate of freight. The mechanical conditions which ensure expedition in long voyages, exclude, to a great extent, the transport of general merchandise; for a large part of the tonnage of the vessel is occupied by the machinery and fuel. The heavy expenses, therefore, of the construction and maintenance of these vessels, must be defrayed by appropriating the profitable tonnage to those objects of transport alone which will bring the highest rate of freight. While the steamer, therefore, has allured from the sailing-vessel the chief part of the passenger traffic, the mails altogether, parcels, and some few objects of general traffic, the latter still continues in undisturbed possession of the transport business of general commerce.

The next step in the improvement of the art must therefore be directed to the construction of another class of steam-vessels, which shall bear to the present steam-ships the same relation which the goods-trains, on the railway, bear to the passenger-trains. As in the case of these goods-trains, expedition must be sacrificed to reduce the cost of transport to the limit which shall enable the merchandise to bear the freight. If the steamer for the general purposes of commerce can be made to exceed the sailing-vessel, in anything approaching to the ratio by which the goods-train on the railway exceeds the waggon or canal-boat, we shall soon see the ocean covered with such steamers, and the sailing-vessel will pass from the hands of the merchant to those of the historian.

17. To render steamers capable of attaining these ends, it will be evidently advisable to adopt measures, to combine the qualities of a sailing-vessel with those of a steamer. The ships must possess such steaming power as may give them that increased expedition, regularity, and punctuality, which, in the existing state of the arts, can only be obtained through that agency; but it is also important that they should accomplish this without robbing them, to any injurious extent, of their present capability of satisfying the wants of commerce.

18. In an early edition of my treatise on the Steam-Engine, published long before screw steam-vessels had attained the state of perfection to which they have now arrived, I stated that no expedient was more likely to accomplish this, than one which would

have for its object the removal of the paddle-wheels now generally used, and the substitution of some description of subaqueous propeller. A great reduction in the dimensions of the machinery, and the surrender to the uses of commerce of that invaluable space which it now occupies within the vessel, are also essential. It is incumbent on the engineer who assumes the high responsibility of the superintendence of such a project, to leave the ship in the full and unimpaired enjoyment of its functions as a sailing-vessel. Let him combine, in short, the agency of steam with the undiminished nautical power of the ship. Let him celebrate the marriage of the steam-engine with the sailing-vessel. If he accomplish this with the skill and success of which the project is susceptible, he may fairly hope that his name will go down to posterity as a benefactor of mankind, united with those of Fulton and Watt.

The actual progress of mechanical science encourages us to hope, that the day is fast approaching when such ideas will be realised —when we shall behold a great highway cut across the wide Atlantic, not as now, subserving to those limited ends, the attainment of which will bear a high expense, but answering all the vast and varied demands of general commerce. Ships which would serve the purposes we have here shadowed out, can never compete in mere speed with vessels in which cargo is nothing, expense disregarded, and expedition everything. Be it so. Leave to such vessels their proper functions; let them still enjoy to some extent the monopoly of the most costly branches of traffic, subsidised as they are by the British treasury. Let the commercial steam-ships, securing equal regularity and punctuality, and probably more frequent despatch, be content with somewhat less expedition. This is consistent with all the analogies of commerce.

There is another consideration which ought not to be omitted. In all great advances in the arts of life, extensive improvements are at first attended with individual loss of greater or less amount. The displacement of capital is almost inevitably attended with this disadvantage. It is the duty, therefore, of the scientific engineer, in the arrangement and adoption of his measures, to consider how these objects may be best attained with the least possible injury to existing interests. To accomplish this will not only be a benefit to the public, but will materially facilitate the realisation of his own objects, by conciliating in their favour those large and powerful interests, whose destruction would be otherwise menaced by them. If, then, in the present case, it is found practicable with advantage to introduce into the present sailing-ships, more especially into those most recently constructed, the

agency of steam, a very important advantage will be gained for the public, and the almost unanimous support and countenance of the commercial community will be secured.

19. To attain the objects here developed, it will be evidently indispensable to remove those impediments, which at once disfigure the appearance and destroy the efficiency of the sailing qualities of the ship, by the enormous and unsightly excrescences projecting from the sides in the shape of paddle-wheels, and the wheel-houses or paddle-boxes, as they are called. These appendages are attended with many evils, the least of which is perhaps the impediment which they present to the progress of the ship.

But the form, magnitude, and position of the propelling machinery, is far from being the only obstacle to the full success of the present steam-vessels, when directed to the general purposes of commerce. The engines themselves, and the boilers, from which the moving power proceeds, and the fuel by which they are worked, occupy the very centre of the vessel, and engross the most valuable part of the tonnage. The chimney, which gives efficacy to the furnaces, is also an unsightly excrescence, and no inconsiderable obstruction.

When long ocean-voyages are contemplated, such as those between New York and the ports of England, there is another serious obstacle, which is especially felt in the westward trip, because of the prevalence of adverse winds. When the vessel starts on its long voyage, it is necessarily laden with a large stock of fuel, which is calculated to meet, not merely the average exigencies of the voyage, but the utmost extremity of adverse circumstances of wind and weather to which it can by possibility be exposed. This fuel is gradually consumed upon the voyage; the vessel is proportionally lightened, and its immersion diminished. If its trim be so regulated that the immersion of its wheels at starting be such as to give them complete efficiency, they may, before the end of the voyage, be almost if not altogether raised out of the water. If, on the other hand, the efficiency of propulsion in the latter part of the voyage be aimed at, they must have such a depth at its commencement as to impair in a serious degree their propelling effect, and to rob the vessel of its proper speed. Under such circumstances, there is no expedient left but compromise. The vessel must start with too great and arrive with too little immersion. There is no alternative, save to abandon altogether the form and structure of the present machinery, and to awaken the inventive genius of the age to supply other mechanical expedients, which shall not be obnoxious to these objections.

In fine, then, we look to the improvement of auxiliary steam power, and the extended use of submerged propellers, as the means

which, in the existing state of the art of steam-navigation, are most likely to extend the benefits of that agent of transport to general commerce.

20. If the form and structure of paddle-wheel steam-vessels be obnoxious to these many serious objections, when considered with reference to the purposes of general commerce, they are still more objectionable when considered with reference to the purposes of national defence. It is undoubtedly a great power with which to invest a vessel of war, to be able to proceed at will, in spite of the opposition of wind or tide, in any direction which may seem most fit to its commander. Such a power would have surpassed the wildest dreams of the most romantic and imaginative naval commander of the last century. To confer upon the vessels of a fleet the power immediately, at the bidding of the commander, to take any position that may be assigned to them relatively to the enemy, or to run in and out of a hostile port at pleasure, or fly with the rapidity of the wind past the guns of formidable forts, before giving them time to take effect upon them—are capabilities which must totally revolutionise all the established principles of naval tactics. But these powers at present are not conferred upon steam-ships, without important qualifications and serious draw-backs. The instruments and machinery from which they are immediately derived are, unfortunately, exposed in such a manner as to render the exercise of the powers themselves hazardous in the extreme. It needs no profound engineering knowledge to perceive that the paddle-wheels are eminently exposed to shot, which, taking effect, would altogether disable the vessel, and leave her at the mercy of the enemy; and the chimney is even more exposed, the destruction of which would render the vessel a prey to the enemy within itself in the shape of fire. But besides these most obvious sources of exposure in vessels of the present form intended as a national defence, the engines and boilers themselves, being more or less above the water line, are exposed so as to be liable to be disabled by shot.

A war steamer, to be free from these objections, should be propelled by subaqueous apparatus. Her engines, boilers, and all other parts of her machinery should be below the water-line. Her fuel should be hard coal, burning without visible smoke, so that her approach may not be discoverable from a distance. Her furnaces might be worked by blowers, so that the chimney might be dispensed with, and thus its liability to be carried away by shot removed.

21. The policy of the British government has been to rely on the commercial steam navy as a means of national defence, in the event of the sudden outbreak of war. By the evidence given

before a committee of the House of Commons in 1850, and the report founded thereupon, it appeared that commercial steamers in general are capable of war service, with no other previous alteration or preparation than such as are easily practicable and expeditiously executed. It was shown that all steamers of 400 tons and upwards would be capable, with some additional strengthening, to carry such pivot guns as are used in war-steamers, and that there are few mercantile steamers of any size, which might not carry an armament such as would render them useful in case of an emergency.

22. The principle on which the steam-engine is applied to the propulsion of ships is the same as that by which oars act in propelling boats. In both cases the propelling instruments having a point or points of reaction on the vessel, are made to drive a mass of water backwards, and the moving force, or momentum, thus imparted to the water from stem to stern, is necessarily attended with a reaction from stern to stem, which, taking effect on the vessel, gives it a corresponding progressive motion.

By the well-known mechanical principle of the composition and resolution of force, it can be demonstrated that whatever force may be imparted to the water by the propeller, such force can be resolved into two elements, one of which is parallel, and the other in a plane at right angles to the keel. The former alone can have a propelling effect, and since the latter is wholly ineffective, the propeller should always be so constructed that its whole force, or at least the chief part of it, shall be employed in driving the water in a direction parallel to the keel from stem to stern.

23. The mechanical expedients by which the power of steam is rendered available for the propulsion of vessels are very various, both as regards the form of the engine which acts upon the propeller, and the form of the propeller itself.

In all cases hitherto reduced to practice, the propeller is a wheel fixed upon a horizontal shaft, to which the engine imparts a motion of continued rotation. The wheel is so constructed that when it revolves it imparts to a volume of water, more or less considerable, a motion either directly backwards, or one whose principal component has that direction. The greater the proportion which this principal component has to the entire force exercised by the propeller, the more effective it will be.

24. The propellers hitherto practically applied in steam-navigation are of two kinds, called *paddle-wheels* and *screws*.

The shaft of the paddle-wheels is fixed horizontally across the vessel, and consequently at right angles to the direction of the keel.

The shaft of the screws is placed horizontally in the vessel parallel to the keel, and directly above it.

The faces of the paddle-wheels look sideways and are consequently parallel to the keel.

The faces of the screws look sternwards, and are consequently at right angles to the keel.

25. The paddle-wheels are in pairs one at each side of the vessel and outside the hull, being supported on the projecting ends of the paddle-shaft, and covered by large semi-cylindrical drums called *paddle-boxes.*

The screws are generally single wheels, within the vessel under its hull, and placed near the stern.

Only the lower parts of the paddle-wheels are immersed. The screws are altogether submerged.

26. The paddle-shaft being carried on each side beyond the timbers of the vessel, the wheels supported by it and revolving with it, are usually constructed like undershot water-wheels, having attached to their rims a number of flat boards called *paddle-boards.* As the wheels revolve, these paddle-boards strike the water, driving it in a direction contrary to that in which it is intended the vessel should be propelled. On the paddle-shaft two cranks are constructed, similar to the crank on the axle of the fly-wheel of a stationary engine. These cranks are generally placed at right angles to each other, so that when either is in its highest or lowest position the other shall be horizontal. They are driven by two steam-engines, which are usually placed in the hull of the vessel below the paddle-shaft. In the earlier steamboats a single steam-engine was used, and in that case the unequal action of the engine on the crank was equalised by a fly-wheel. This, however, has been long since abandoned in European vessels, and the use of two engines is now almost universal. By the relative position of the cranks it will be seen, that when either crank is at its dead point the other will be in one of the positions most favourable to its action, and in all intermediate positions, the relative efficiency of the cranks will be such as to render their combined action very nearly uniform.

The steam-engines used to impel vessels may be either condensing engines, similar to those of Watt, and such as are used in manufactures generally, or they may be non-condensing and high-pressure engines, similar in principle to those used on railways. Low-pressure condensing engines are, however, universally used for marine purposes in Europe, and to a great extent in the United States. In the latter country, however, high-pressure engines are also used in some of the river steamers.

27. The arrangement of the parts of a marine engine differs in

some respects from that of a land engine. The limitation of space, which is unavoidable in a vessel, renders greater compactness necessary. The paddle-shaft on which the cranks to be driven by the engine are constructed being very little below the deck of the vessel, the beam, if there be one, and connecting rod could not be placed in the position in which they usually are in land engines, without carrying the machinery to a considerable elevation above the deck. This is done in the steam-boat engines used on the American rivers; but it would be inadmissible in steam-boats in general, and more especially in sea-going steamers. The connecting rods, therefore, instead of being presented downwards towards the cranks which they drive, must, in steam-vessels, be presented upwards, and the impelling force be received from below. If, under these circumstances, the beam were in the usual position above the cylinder and piston-rod, it must necessarily be placed between the engine and the paddle-shaft. This would require a depth for the machinery which would be incompatible with the magnitude of the vessel. The beam, therefore, of marine engines, instead of being above the cylinder and piston, is placed below them. To the top of the piston rods, cross-pieces are attached, of greater length than the diameter of the cylinders, so that their extremities shall project beyond the cylinders. To the ends of these cross-pieces are attached by joints the rods of a parallel motion: these rods are carried downwards, and are connected with the ends of two beams below the cylinder, and placed on either side of it. The opposite ends of these beams are connected by another cross-piece, to which is attached a connecting rod, which is continued upwards to the crank-pin, to which it is attached, and which it drives. Thus the beam, parallel motion, and connecting rod of a marine engine, are similar to those of a land engine, only that they are turned upside down; and in consequence of the impossibility of placing the beam directly over the piston rod, two beams and two systems of parallel motion are provided, one on each side of the engine, acted upon by, and acting on the piston rod and crank by cross-pieces.*

The proportion of the cylinders differs from that usually observed in land engines for like reasons. The length of the cylinder of land engines is generally greater than its diameter, in the proportion of about two to one. The cylinders of marine engines are, however, commonly constructed with a diameter greater than their length. In proportion, therefore, to their power their stroke is shorter, which infers a corresponding short-

* We must assume that the reader of the present Tract has already rendered himself familiar with the several Tracts on Steam and the Steam Engine, already published in the Museum.

ness of crank and a greater limitation of play of all the moving parts in the vertical direction. The valves and the gearing by which they are worked, the air-pump, the condenser and other parts of the marine engines, do not differ in principle from those already described in land engines.

These arrangements will be more clearly understood by reference to fig. 1, in which is represented a longitudinal section of one of the many varieties of beam engine, with its boiler as placed in a steam-vessel. The sleepers of oak, supporting the engine, are represented at X, the base of the engine being secured to these by bolts passing through them and the bottom timbers of the vessel; S is the steam-pipe leading from the steam-chest in the boiler to the slides *c*, by which it is admitted to the top and bottom of the cylinder. The condenser is represented at B, and the air-pump at E. The hot well is seen at F, from which the feed is taken for the boiler; L is the piston-rod connected by the parallel motion *a*, with the beam H, working on a centre K, near the base of the engine. The other end of the beam I drives the connecting rod M, which extends upwards to the crank, which it works upon the paddle-shaft O. Q R is the framing by which the engine is supported. The beam here exhibited is shown on dotted lines as being on the further side of the engine. A similar beam similarly placed, and moving on the same axis, must be understood to be at this side connected with the cross-head of the piston in like manner by a parallel motion, and with a cross-piece attached to the lower end of the connecting rod and to the opposite beam. The eccentric which works the slides is placed upon the paddle-shaft O, and the connecting arm which drives the slides may be easily detached when the engine requires to be stopped. The section of the boiler, grate, and flues is represented at W U. The safety-valve *y* is enclosed beneath a pipe carried up beside the chimney, and is inaccessible to the engine man; *h* are the cocks for blowing the salted water from the boiler, and I I the feed-pipe.

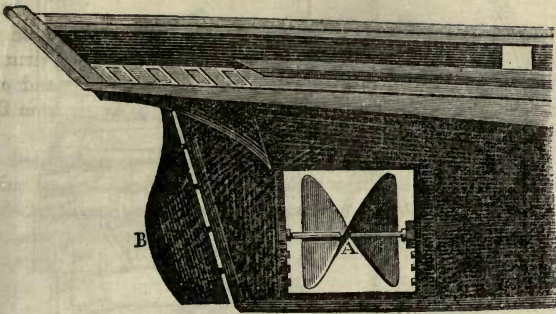


Fig. 2.—FORM AND POSITION OF THE SCREW.

STEAM NAVIGATION.

CHAPTER II.

28. Arrangement of the engine-room; governor and other regulating parts omitted.—29. Flue boilers and tubular boilers.—30. Construction of flue boilers.—31. Tubular boilers.—32. Indications of engineering ignorance.—33. Number and dimensions of tubes.—34. Incrustation produced by sea water.—35. Hydrometric indicators.—37. Thermometric indicators.—38. Seaward's contrivance.—39. Brine-pumps.—40. Blowing out.—41. To detach the scale.—42. Effect of corrosion.—43. Efficiency and economy of fuel.—44. Coating the boiler and pipes with felt.

28. The general arrangement of the engine-room of a steam-vessel is represented in fig. 3, page 131.

The nature of the effect required to be produced by marine engines, does not render either necessary or possible that great regularity of action, which is indispensable in a steam-engine applied to the purposes of manufacture. The agitation of the surface of the sea will cause the immersion of the paddle-wheels to be subject to great variation, and the resistance produced by the water to the engine will undergo a corresponding change. The governor, therefore, and other parts of the apparatus, contrived for giving to the engine that great regularity required in manufactures, are omitted in nautical engines, and nothing is introduced save what is necessary to maintain the machine in its full working efficiency.

Marine boilers are constructed in forms so infinitely various, that, in a notice so brief and popular as the present, we can only indicate some of their more general arrangements, and aid the

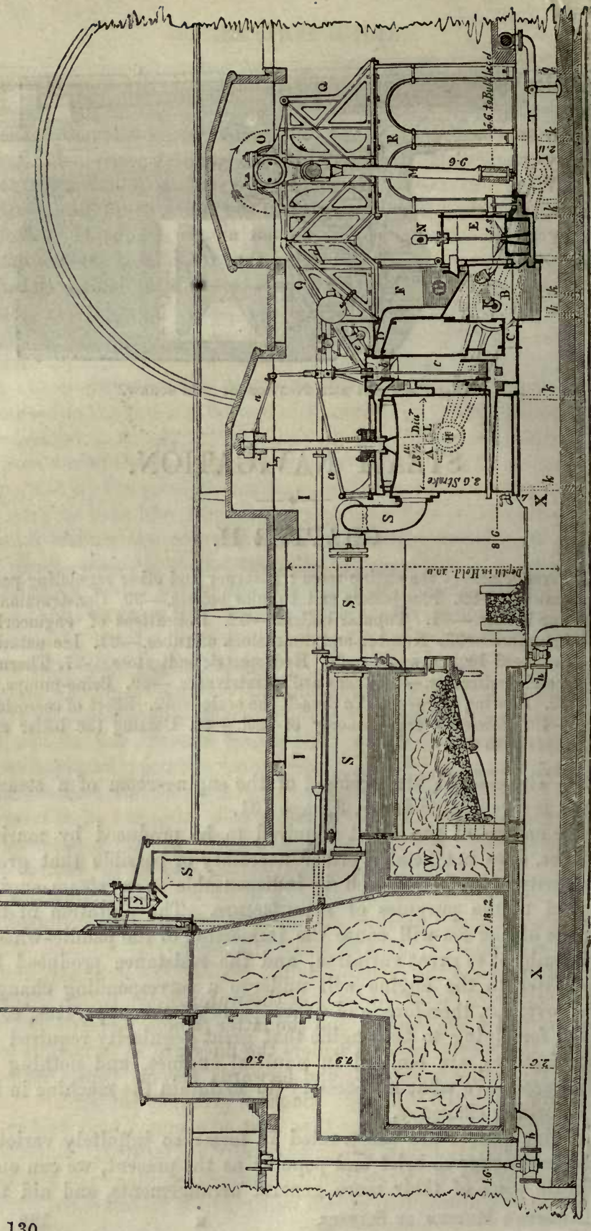
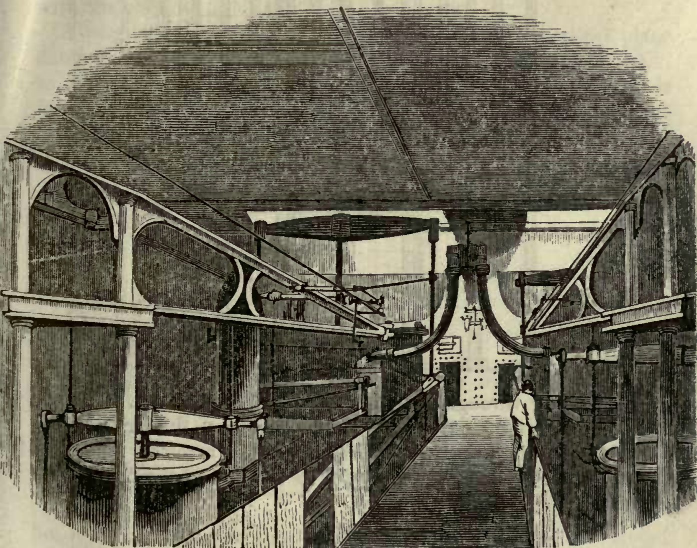


Fig. 1.

explanation by figures representing examples of particular classes of them.

29. To save space, they are constructed so as to produce the necessary quantity of steam, within the smallest possible dimensions. With this view a more extensive surface in proportion to the capacity of the boiler is exposed to the action of the fire. The flues, by which the flame and heated air are conducted to the chimney, are generally so constructed that the heated air issuing from the furnaces may be made to pass through the boiler, either

Fig. 3.



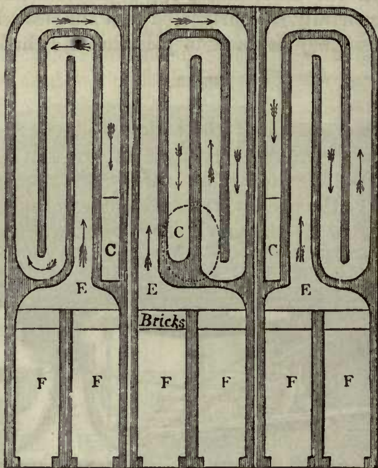
by a series of oblong narrow passages with flat sides, called *flues*, or by a multitude of tubes of small diameter, the one and the other leading from the furnaces to the base of the chimney, and being everywhere below the level of the water in the boiler. The former are called *flue boilers*, and the latter *tubular boilers*.

30. In the former class of boilers the flues are so formed as to traverse the boiler backwards and forwards several times before they terminate in the chimney. Such an arrangement renders the expense of the boilers greater than that of common land boilers, but their steam-producing power is greatly augmented. Experiments made by Mr. Watt, at Birmingham, proved that such boilers with the same consumption of fuel will produce, as compared with

common land boilers, an increased evaporation in the proportion of about three to two.

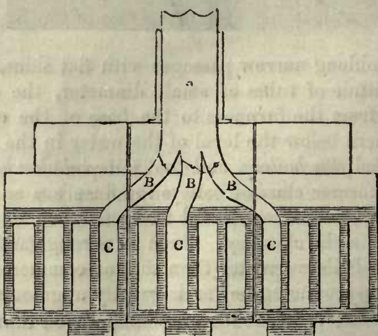
The form and arrangement of the water-spaces and flues in flue boilers are infinitely various. The sections of such boilers are exhibited in figs. 4, 5, 6. A section made by a horizontal

Fig. 4.



plane passing through the flues is exhibited in fig. 4. The furnaces F communicate in pairs with the flues E, the air following the course through the flues represented by the arrows. The flue E passes to the back of the boiler, then returns to the front, then

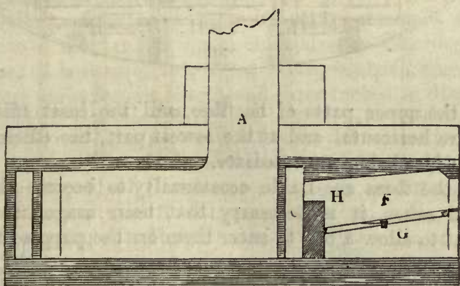
Fig. 5.



to the back again, and is finally carried back to the front, where it communicates at C with the curved flue B, represented in the transverse vertical section, fig. 5. This curved flue B finally terminates in the chimney A. There are, in this case, three independent boilers, each worked by two furnaces communicating with the same system of flues; and in the curved flues B, fig. 5, by which the air is finally conducted through the chimney, are placed three independent dampers, by means of which the furnace of each boiler can be regulated independently of the other, and by which each boiler may be separately detached from communication with the chimney.

A longitudinal section of the boiler, made by a vertical plane extending from the front to the back, is given in fig. 6, where F, as before, is the furnace, G the grate-bars sloping downwards from the front to the back, H the fire-bridge, C the commencement of the flues, and A the chimney. An elevation of the front of the

Fig. 6.



boiler is represented in fig. 7, showing two of the fire-doors closed and the other two removed, displaying the position of the grate-bars in front. Small openings are also provided, closed by proper doors, by which access can be had to the under-side of the flues, between the foundation timbers of the engine, for the purpose of cleaning them.

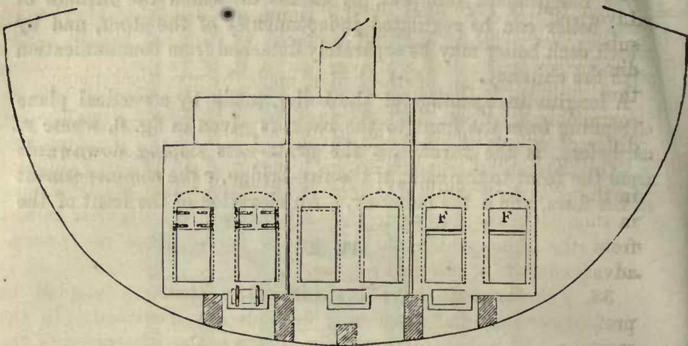
Each of these boilers can be worked independently of the others. By this means, when at sea, the engine may be worked by any two of the three boilers, while the third is being cleaned and put in order.

In the boilers here represented the flues are all upon the same level, winding backwards and forwards without passing one above the other. In other boilers, however, the flues, after passing backwards and forwards near the bottom of the boiler, turn

upwards and pass backwards and forwards through a level of the water nearer its surface, finally terminating in the chimney. More heating surface is thus obtained with the same capacity of boiler.

It is found in practice, that the most efficient parts of the flue-surface for the generation of steam, are those which are horizontal

Fig. 7.



and at the upper parts of the flue, and the least efficient those which are horizontal and at the lowest part, the efficiency of the vertical sides being intermediate.

Since the flues are liable occasionally to become choked with soot and ashes, it is necessary that their magnitude shall be sufficient to allow a boy to enter them for the purpose of cleaning them.

31. Tubular marine boilers are constructed on a principle precisely similar to that of locomotive boilers, described in a former Tract. The flame and gaseous products of combustion, issuing from the furnace at a very elevated temperature, pass through a great number, sometimes several hundred, tubes of iron or brass, of about three inches diameter, which traverse the boiler below the level of the water in it, so that before they enter the chimney their temperature is reduced to a comparatively low point, the heat they thus lose being taken up by the water surrounding the tubes.

Flue boilers have the advantage over tubular boilers in being cheaper and more durable. With the same evaporating power they are however one-third larger and heavier, and consequently occupy a greater portion of the tonnage, and produce, other things being the same, a proportionally greater displacement, the latter condition augmenting the resistance, and therefore either diminishing the speed, or increasing the consumption of fuel.

32. There cannot be a more striking proof of the ignorance of general principles which prevails, respecting this branch of steam engineering, than the endless variety of forms and proportions which are adopted in the boilers and furnaces which are constructed, not only by different engineers but by the same engineer, for steamers of like power and capacity, and even for the same steamer at different times. Thus the original boilers of the *Great Western*, built for the New York and Bristol or Liverpool voyage, were of the common flue sort. They were subsequently taken out and replaced by tubular boilers. The dimensions and relative proportions of these two sets of boilers, thus supplied to the same vessel for the same voyage, differing as completely one from the other as if they had been designed for different vessels and different voyages.

On contemplating engineering proceedings, such as are exhibited in the preceding table, it is impossible to deny that practical men in such cases are groping in the dark, without the slightest benefit from the light which they ought to derive, from the present advanced state of physical science.

33. Tubular flues have been in many steamers adopted in preference to the flat and longer flues already described. In the second set of boilers of the *Great Western* above mentioned, the tubes were eight feet in length and three inches in diameter. In the boilers of the steamer *Ocean*, which are also tubular, the following are the principal dimensions:—

Boilers:	
Number	3
Length	14 feet.
Breadth	$19\frac{1}{2}$ feet.
Furnaces:	
Number	7
Length	7 feet.
Breadth	$2\frac{11}{12}$ feet.
Tubes:	
Material	Iron.
Number	378
Length	9 feet
Diameter	$3\frac{1}{4}$ inches.
Cylinders:	
Number	2
Diameter	56 inches.
Stroke	$5\frac{1}{2}$ feet.
Pressure of steam above atmosphere	$4\frac{1}{2}$ lbs. per in.
Consumption of coal per hour	18 cwt.

Among the more recent specifications of the machinery of marine engines submitted to the Admiralty, are some in which the boilers are traversed by nearly 2000 tubes of $3\frac{1}{2}$ inches external diameter, and five feet in length, giving a total heating surface of about 9000 square feet.

34. A formidable difficulty in the application of the steam-engine to sea voyages has arisen from the necessity of supplying the boiler with sea water instead of fresh water. The sea water is injected into the condenser for the purpose of condensing the

steam, and, mixed with the condensed steam, it is thence conducted as feeding water into the boiler.

Sea water holds, as is well known, certain saline and alkaline substances in solution, the principal of which is muriate of soda, or common salt. Ten thousand grains of pure sea water contain two hundred and twenty grains of common salt, the remaining ingredients being thirty-three grains of sulphate of soda, forty-two grains of muriate of magnesia, and eight grains of muriate of lime. The heat which converts pure water into steam does not at the same time evaporate those salts which the water holds in solution. As a consequence it follows, that, as the evaporation in the boiler is continued, the salt, which was held in solution by the water which has been evaporated, remains in the boiler, and enters into solution with the water remaining in it. The quantity of salt contained in sea water being considerably less than that which water is capable of holding in solution, the process of evaporation for some time is attended with no other effect, than to render the water in the boiler a stronger solution of salt. If, however, this process be continued, the quantity of salt retained in the boiler having constantly an increasing proportion to the quantity of water, it must at length render the water in the boiler a saturated solution; that is, a solution containing as much salt as, at the actual temperature, it is capable of holding in solution. If, therefore, the evaporation be continued beyond this point, the salt disengaged from the water evaporated, instead of entering into solution with the water remaining in the boiler, will be precipitated in the form of sediment; and if the process be continued in the same manner, the boiler would at length become a mere salt-pan.

But besides the deposition of salt sediment in a loose form, some of the constituents of sea water having an attraction for the iron of the boiler, collect upon it in a scale or crust, in the same manner as earthy matters, held in solution by spring water, are observed to form and become incrusted on the inner surface of land-boilers and of common culinary vessels.

The coating of the inner surface of a boiler by incrustation, and the collection of salt sediment in its lower parts, are attended with effects highly injurious to the materials of the boiler. The crust and sediment thus formed within the boiler are almost non-conductors of heat, and placed, as they are, between the water contained in the boiler and the metallic plates which form it, they obstruct the passage of heat from the outer surface of the plates in contact with the fire, to the water. The heat, therefore, accumulating in the boiler-plates so as to give them a much higher temperature than the water within the boiler, has the effect of softening them, and by the unequal temperature which will thus

be imparted to the lower plates which are incrusted, compared with the higher parts which may not be so, an unequal expansion is produced, by which the joints and seams of the boiler, are loosened and opened, and leaks produced.

These injurious effects can only be prevented by either of two methods; first, by so regulating the feed of the boiler that the water it contains shall not be suffered to reach the point of saturation, but shall be so limited in its degree of saltness that no injurious incrustation or deposit shall be formed; secondly, by the adoption of some method by which the boiler may be worked with fresh water. This end can only be attained by condensing the steam by a jet of fresh water, and working the boiler continually by the same water, since the supply of fresh water sufficient for a boiler worked in the ordinary way, could never be commanded at sea.

The method by which the saltness of the water in the boiler is most commonly prevented from exceeding a certain limit, has been to discharge from the boiler into the sea a certain quantity of over-salted water, and to supply its place by sea water introduced into the condenser through the injection-cock, for the purpose of condensing the steam, this water being mixed with the steam so condensed, and being, therefore, a weaker solution of salt than common sea water. To effect this, cocks called *blow-off cocks* are usually placed in the lower parts of the boiler, where the over-salted, and therefore heavier, parts of the water collect. The pressure of the steam and incumbent weight of the water in the boiler force the lower strata of water out through these cocks; and this process, called *blowing out*, is, or ought to be practised at such intervals as will prevent the water from becoming over-salted. When the salted water has been blown out in this manner, the level of the water in the boiler is restored by a feed of corresponding quantity.

This process of blowing out, on the due and regular observance of which the preservation and efficiency of the boiler mainly depend, is too often left at the discretion of the engineer, who is, in most cases, not even supplied with the proper means of ascertaining the extent to which the process should be carried. It is commonly required that the engineer should blow out a certain portion of the water in the boiler every two hours, restoring the level by a feed of equivalent amount; but it is evident that the sufficiency of the process, founded on such a rule, must mainly depend on the supposition, that the evaporation proceeds always at the same rate, which is far from being the case with marine boilers.

35. An indicator, by which the saltness of the water in the boiler would always be exhibited, ought to be provided, and the

process of blowing out should be regulated by the indications of that instrument. To blow out more frequently than is necessary is attended with a waste of fuel; for hot water is thus discharged into the sea while cold water is introduced in its place, and consequently all the heat necessary to produce the difference of the temperatures of the water blown out, and the feed introduced, is lost. If, on the other hand, the process of blowing out be observed less frequently than is necessary, then more or less incrustation and deposit may be produced, and the injurious effects already described ensue.

36. As the specific gravity of water holding salt in solution is increased with every increase of the strength of the solution, any form of hydrometer capable of exhibiting a visible indication of the specific gravity of the water contained in the boiler, would serve the purpose of an indicator, to show when the process of blowing out is necessary, and when it has been carried to a sufficient extent. The application of such instruments, however, would be attended with some practical difficulties in the case of sea boilers.

37. The temperature at which a solution of salt boils under a given pressure varies considerably with the strength of the solution; the more concentrated the solution is, the higher will be its boiling temperature under the same pressure. A comparison, therefore, of a steam-gauge attached to the boiler, and a thermometer immersed in it, showing the pressure and the temperature, would always indicate the saltness of the water; and it would not be difficult so to graduate these instruments as to make them at once show the degree of saltness.

If the application of the thermometer be considered to be attended with practical difficulty, the difference of pressures under which the salt water of the boiler and fresh water of the same temperature boil, might be taken as an indication of the saltness of the water in the boiler, and it would not be difficult to construct upon this principle a self-registering instrument, which would not only indicate but record from hour to hour the degree of saltness of the water. A small vessel of distilled water being immersed in the water of the boiler would always have the temperature of that water, and the steam produced from it communicating with a steam-gauge, the pressure of such steam would be indicated by that gauge, while the pressure of the steam in the boiler under which pressure the salted water boils might be indicated by another gauge. The difference of the pressures indicated by the two gauges would thus become a test, by which the saltness of the water in the boiler would be measured. The two pressures might be made to act on opposite ends of the same

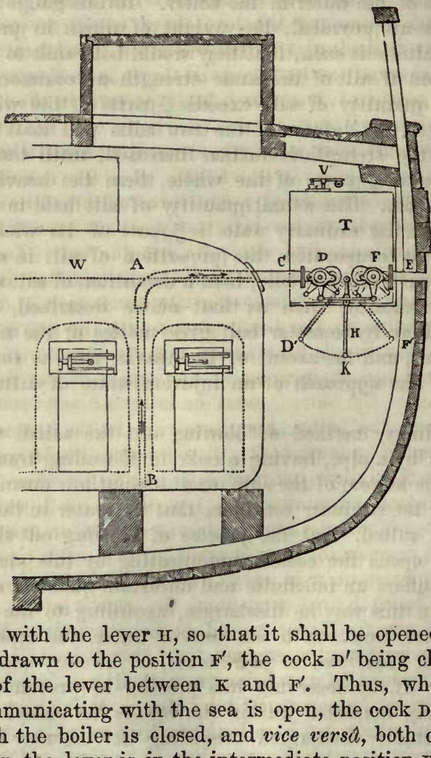
column of mercury contained in a siphon tube, and the difference of the levels of the two surfaces of the mercury, would thus become a measure of the saltness of the water in the boiler. A self-registering instrument, founded on this principle, formed part of the self-registering steam-log which I proposed to introduce into steam-vessels some time since.

38. The Messrs. Seaward of Limehouse adopted, in some of their engines, a method of indicating the saltness of the water, and of measuring the quantity of salted water or brine discharged by blowing out. A glass-gauge, similar in form to that already described in land engines, is provided, to indicate the position of the surface of the water in the boiler. In this gauge two hydrometer balls are provided, the weight of which in proportion to their magnitude is such, that they would both sink to the bottom in a solution of salt of the same strength as common sea water. When the quantity of salt exceeds $\frac{5}{32}$ parts of the whole weight of the water, the lighter of the two balls will float to the top; and when the strength is further increased until the proportion of salt exceeds $\frac{6}{32}$ parts of the whole, then the heavier ball will float to the top. The actual quantity of salt held in solution by sea water in its ordinary state is $\frac{1}{32}$ part of its whole weight; and when by evaporation the proportion of salt in solution has become $\frac{9}{32}$ parts of the whole, then a deposition of salt commences. With an indicator such as that above described, the ascent of the lighter hydrometer ball gives notice of the necessity for blowing out, and the ascent of the heavier may be considered as indicating the approach of an injurious state of saltness in the boiler.

The ordinary method of blowing out the salted water from a boiler is by a pipe, having a cock in it leading from the boiler through the bottom of the ship, or at a point low down at its side. Whenever the engineer considers that the water in the boiler has become so salted, that the process of blowing out should commence, he opens the cock communicating by this pipe with the sea, and suffers an indefinite and uncertain quantity of water to escape. In this way he discharges, according to the magnitude of the boiler, from two to six tons of water, and repeats this at intervals of from two to four hours, as he may consider to be sufficient. If, by observing this process, he prevents the boiler from getting incrusted during the voyage, he considers his duty to be effectually discharged, forgetting that he may have blown out many times more water than is necessary for the preservation of the boiler, and thereby produced a corresponding and unnecessary waste of fuel. In order to limit the quantity of water discharged, Messrs. Seaward adopted the following method. In

fig. 8 is represented a transverse section of a part of a steam-vessel; W is the water-line of the boiler, B is the mouth of a blow-off pipe, placed near the bottom of the boiler. This pipe rises to A, and turning in the horizontal direction, A C, is conducted to a tank T, which contains exactly a ton of water. This pipe communicates with the tank by a cock D, governed by a lever H. When this lever is moved to D′, the cock D is open, and when it is moved to K, the cock D is closed. From the same tank there proceeds another pipe E, which issues from the side of the vessel into the sea, governed by a cock F, which is likewise put in

Fig. 8.



connection with the lever H, so that it shall be opened when the lever H is drawn to the position F′, the cock D′ being closed in all positions of the lever between K and F′. Thus, whenever the cock F communicating with the sea is open, the cock D communicating with the boiler is closed, and *vice versâ*, both cocks being closed when the lever is in the intermediate position K. By this arrangement the boiler cannot, by any neglect in blowing off, be left in communication with the sea, nor can more than a ton of water be discharged except by the immediate act of the

engineer. The injurious consequences are thus prevented which sometimes ensue, when the blow-off cocks are left open by any neglect on the part of the engineer. When it is necessary to blow off, the engineer moves the lever H to the position D′. The pressure of the steam in the boiler on the surface of the water forces the salted water or brine up the pipe B A, and through the open cock C into the tank, and this continues until the tank is filled: when that takes place, the lever is moved from the position D′ to the position F′, by which the cock D is closed, and the cock F opened. The water in the tank flows through the pipe E into the sea, air being admitted through the valve V, placed at the top of the tank, opening inwards. A second ton of brine is discharged by moving the lever back to the position D′, and subsequently returning it to the position F′; and in this way the brine is discharged ton by ton, until the supply of water from the feed which replaces it has caused both the balls in the indicator to sink to the bottom.

39. A different method of preserving the requisite freshness of the water in the boiler was adopted by Messrs. Maudslay and Field. Pumps called *brine-pumps* are put into communication with the lower part of the boiler, and so constructed as to draw the brine therefrom, and drive it into the sea. These brine-pumps are worked by the engine, and their operation is constant. The feed-pumps are likewise worked by the engine, and they bear such a proportion to the brine-pumps that the quantity of salt discharged in a given time in the brine is equal to the quantity of salt introduced in solution by the water of the feed-pumps. By this means the same actual quantity of salt is constantly maintained in the boiler, and consequently the strength of the solution remains invariable. If the brine discharged by the brine-pumps contains $\frac{5}{32}$ parts of salt, while the water introduced by the feed-pumps contains only $\frac{1}{32}$ part, then it is evident that five cubic feet of the feeding-water will contain no more salt than is contained in one cubic foot of brine. Under such circumstances the brine-pumps would be so constructed as to discharge $\frac{1}{5}$ of the water introduced by the feed-pumps, so that $\frac{4}{5}$ of all the water introduced into the boiler would be evaporated, and rendered available for working the engine.

To save the heat of the brine, a method has been adopted in the marine engines constructed by Messrs. Maudslay and Field, similar to one which has been long practised in steam-boilers, and in various apparatus for the warming of buildings. The current of heated brine is conducted from the boiler through a tube which is contained in another, through which the feed is introduced. The warm current of brine, therefore, as it passes out,

imparts a considerable portion of its heat to the cold feed which comes in; and it is found that by this expedient the brine discharged into the sea may be reduced to a temperature of about 100°.

This expedient is so effectual, that when the apparatus is properly constructed, and kept in a state of efficiency, it may be regarded as nearly a perfect preventive against the incrustation, and the deposition of salt in the boilers, and is not attended with any considerable waste of fuel.

40. It is maintained by some practical men, that the economy of heat effected by brine-pumps, such as have been just described, is more than counterbalanced by the risk which attends them, if not accompanied by proper precautions. The pipes through which the salted water is discharged are, it is said, apt to get choked, in which case the pumps will necessarily cease to act, though they appear to the engineer to do so; and thus the water in the boiler may become salted to any extent without the knowledge of the engineer. When the process of *blowing out* is executed in the ordinary way, without brine-pumps, the engineer looks at his water-gauge and keeps the blow-off cock open, until the water level has fallen to the required point. Under these circumstances there is a certainty of having discharged from the boiler a certain quantity of salted water, a certainty which does not exist in the case of a continuous discharge of water by brine-pumps.

Such expedients, therefore, it is contended, should always be accompanied by some indicator, which shall show the degree of saltness of the water in the boiler, such as we shall presently explain.

41. In practice, if a marine boiler be regularly attended to, and the salted water be discharged either by the common method of blowing-off cocks or by brine-pumps, or any other expedient which shall impose the necessary limit on the degree of concentration of water in the boiler, the evil arising from incrustation will be quite inconsiderable.

A scale will in all cases be formed on the inner surface of the boilers, which must be removed from time to time when the vessel is in port. The best method of effecting this is by lighting some shavings, or other light and flaming combustible, in the furnaces when the boilers are empty and the safety-valves open. The expansion of the metal by the heat thus produced being greater than that of the matter composing the scale, the latter will be detached and will fall in pieces to the bottom of the boiler, from which it can be withdrawn with the water at the man-holes.

In some cases, however, it will be preferable to detach the scale by the hammer or chisel.

42. It is a great error to suppose that incrustation is either the

sole or principal cause of the rapid destruction of marine boilers. If it were so, it would necessarily happen that marine boilers in which expedients are adopted by which fresh water is used, or even those in which the process of blowing out has been regularly observed, and in which the scale is detached before it is allowed to thicken to an injurious extent, would last as long, or nearly as long, as land boilers. It is found, however, that the boilers in which these expedients are adopted with the greatest effect and regularity are, nevertheless, less durable in a very large proportion than land boilers. Thus, while a land boiler will last for twenty years, a marine boiler, similarly constructed, will, even with the greatest care, be worn out in four or five years.

The cause of this rapid destruction of the boiler is corrosion, but how this corrosion is produced is a question which has not hitherto been satisfactorily answered. It is contended that this is not to be ascribed to any chemical action of the sea water on the iron, inasmuch as the flues of marine boilers rarely show any deterioration from this cause, and even in worn-out marine boilers the hammer-marks on the flues are as conspicuous as when they are fresh from the boiler-maker. The thin film of scale which covers the interior surface would rather protect the iron from the action of the water. In fine, the seat of the corrosion is almost never those parts of the boiler which are in contact with the water. It is that part of the metal which includes the steam space that exhibits corrosion; but even there the effect is so irregular, that no data can be obtained by which the cause can be satisfactorily traced. The part which is most rapidly corroded in one boiler is not at all affected in another; and in some cases we find one side of the steam-chest attacked, the other side being untouched. Sometimes the iron exfoliates in flakes, while in others it appears as though it were eaten away by an acid.

43. In the application of the steam-engine to the propulsion of vessels in voyages of great extent, the economy of fuel acquires an importance greater than that which appertains to it in land engines, even in localities the most removed from coal-mines, and where its expense is greatest. The practical limit to steam voyages being determined by the greatest quantity of coals which a steam vessel can carry, every expedient by which the efficiency of the fuel can be increased becomes a means, not merely of a saving of expense, but of an increased extension of steam-power to navigation. Much attention has been bestowed on the augmentation of the duty of engines in the mining districts of Cornwall, where the question of their efficiency is merely a question of economy; but far greater care should be given to this subject, when the practicability of maintaining intercourse by steam

between distant points of the globe, will perhaps depend on the effect produced by a given quantity of fuel. So long as steam navigation was confined to river and channel transport and to coasting voyages, the speed of the vessel was a paramount consideration, at whatever expenditure of fuel it might be obtained; but since steam navigation has been extended to ocean voyages, where coals must be transported sufficient to keep the engine in operation for a long period of time without a fresh relay, greater attention has been bestowed upon the means of economising it.

Much of the efficiency of fuel must depend on the management of the fires, and therefore on the skill and care of the stokers. Formerly the efficiency of firemen was determined by the abundant production of steam; and so long as the steam was evolved in superabundance, however it might have blown off to waste, the duty of the stoker was considered as well performed. The regulation of the fires according to the demands of the engine was not thought of, and whether much or little steam was wanted, the duty of the stoker was to urge the fires to their extreme limit.

Since the resistance opposed by the action of the paddle-wheels of a steam-vessel varies with the state of the weather, the consumption of steam in the cylinders must undergo a corresponding variation; and if the production of steam in the boilers be not proportioned to this, the engines will either work with less efficiency than they might do under the actual circumstances of the weather, or more steam will be produced in the boilers than the cylinders can consume, and the surplus will be discharged to waste through the safety valves. The stokers of a marine engine, therefore, to perform their duty with efficiency, and obtain from the fuel the greatest possible effect, must discharge the functions of a self-regulating furnace, such as has been already described: they must regulate the force of the fires by the amount of steam which the cylinders are capable of consuming, and they must take care that no unconsumed fuel is allowed to be carried away from the ash-pit.

44. Formerly the heat radiated from every part of the surface of the boiler was allowed to go to waste, and to produce injurious effects on those parts of the vessel to which it was transmitted. This evil, however, has been removed by coating the boilers, steam-pipes, &c., of steam-vessels with felt, by which the escape of heat from the surface of the boiler is very nearly, if not altogether, prevented. This felt is attached to the boiler surface by a thick covering of white and red lead. This expedient was first applied in the year 1818 to a private steam vessel of Mr. Watt's, called the Caledonia; and it was subsequently adopted in another vessel, the machinery of which was constructed at Soho, called the James Watt.

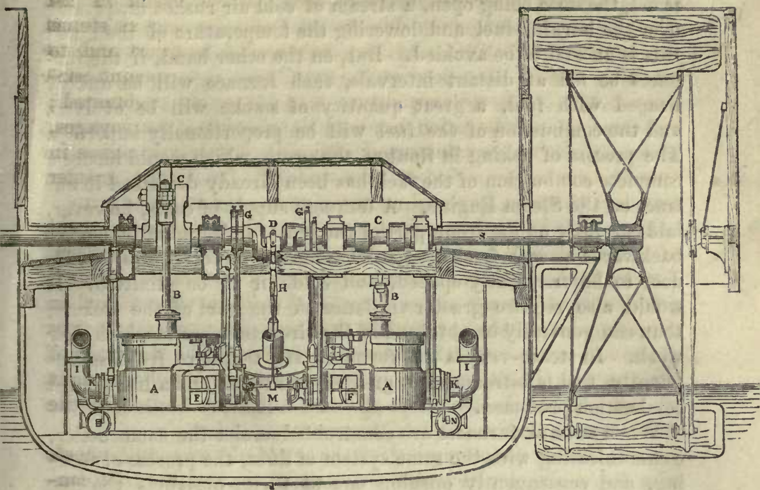


Fig. 10.

STEAM NAVIGATION.

CHAPTER III.

45. Economy of fuel.—46. Width and depth of furnace.—47. Advantage of expansive action.—48. Siamese engines.—49. Simplified arrangements.—50. Number and position of cylinders.—51. Proportion of diameter to stroke.—52. Oscillating engines.—53. Engines of the Peterhoff.—54. Propellers.—55. The common paddle-wheels.—56. Feathering paddles.—57. Morgan's paddle-wheel.—58. Field's split paddles.—59. American paddle-wheel.—60. Practical objections to feathering paddles.—61. Proportion of marine engines.—62. Submerged propellers.—63. Their disadvantages.—64. Screw-propellers.—65. Pitch and slip.—66. Manner of mounting screw-propellers.—67. Their various forms.

45. The economy of fuel depends in a great degree on the arrangement of the furnaces, and the method of feeding them. In general, each boiler is worked by two or more furnaces communicating with the same system of flues. While the furnace

is fed, the door being open, a stream of cold air rushes in, passing over the burning fuel and lowering the temperature of the flues: this is an evil to be avoided. But, on the other hand, if the furnaces be fed at distant intervals, each furnace will be unduly heaped with fuel, a great quantity of smoke will be evolved, and the combustion of the fuel will be proportionally imperfect. The process of coking in front of the grate, which would insure a complete combustion of the fuel, has been already described in our tract on the Steam Engine. A frequent supply of coals, however, laid carefully on the front part of the grate, and gradually pushed backwards as each fresh feed is introduced, would require the fire door to be frequently opened, and cold air to be admitted. It would also require greater vigilance on the part of the stokers, than can generally be obtained in the circumstances in which they work. In steam-vessels the furnaces are therefore fed less frequently, fuel is introduced in greater quantities, and a less perfect combustion produced.

When several furnaces are constructed under the same boiler, communicating with the same system of flues, the process of feeding, and consequently opening one of them, obstructs the due operation of the others, for the current of cold air which is thus admitted into the flues checks the draught, and diminishes the efficiency of the furnaces in operation. It was formerly the practice in vessels exceeding one hundred horse-power, to place four furnaces under each boiler, communicating with the same system of flues. Such an arrangement was found to be attended with a bad draught in the furnaces, and therefore to require a greater quantity of heating surface to produce the necessary evaporation. This entailed upon the machinery the occupation of more space in the vessel in proportion to its power; it has therefore been more recently the practice to give a separate system of flues to each pair of furnaces, or, at most, to every three furnaces. When three furnaces communicate with a common flue, two will always be in operation, while the third is being cleared out; but if the same quantity of fire were divided among two furnaces, then the clearing out of one would throw out of operation half the entire quantity of fire, and during the process the evaporation would be injuriously diminished.

46. It is found by experience, that the side plates of furnaces are liable to more rapid destruction than their roofs, owing, probably, to a greater liability to deposit. Furnaces, therefore, should not be made narrower than a certain limit. Great depth from front to back is also attended with practical inconvenience, as it renders firing tools of considerable length, and a corresponding extent of stoking room necessary. It is recommended by those who have had

much practical experience in steam-vessels, that furnaces six feet in depth from front to back should not be less than three feet in width to afford means of firing with as little injury to the side plates as possible, and of keeping the fires in the condition necessary for the production of the greatest effect. The tops of the furnaces scarcely ever decay, and are seldom subject to an alteration of figure, unless the level of the water be allowed to fall below them.

47. The method by which the greatest quantity of practical effect can be obtained from a given quantity of fuel must, however, mainly depend on the extended application of the expansive principle. This has been the means by which an extraordinary amount of duty has been obtained from the Cornish engines. The difficulty of the application of this principle in marine engines, has arisen from the objections entertained in Europe to the use of steam of high-pressure, under the circumstances in which the engine must be worked at sea. To apply the expansive principle, it is necessary that the moving power at the commencement of the stroke shall considerably exceed the resistance, its force being gradually attenuated till the completion of the stroke, when it will at length become less than the resistance. This condition may, however, be attained with steam of limited pressure, if the engine be constructed with a sufficient quantity of piston surface.

48. This method of rendering the expansive principle available at sea, and compatible with low-pressure steam, was projected and executed by Messrs. Maudslay and Field. Their improvement consists in adapting two steam cylinders in one engine, in such a manner that the steam shall act simultaneously on both pistons, causing them to ascend and descend together. The piston-rods are both attached to the same horizontal cross-head, whereby their combined action is applied to one crank by means of a connecting-rod placed between the pistons.

A section of such an engine (which has been called the Siamese engine), made by a plane passing through the two piston-rods P P′ and cylinders, is represented in fig. 9. The piston-rods are attached to a cross-head C, which ascends and descends with them. This cross-head drives upwards and downwards an axle D, to which the lower end of the connecting-rod E is attached. The other end of the connecting-rod drives the crank-pin F, and imparts revolution to the paddle-shaft G. A rod H conveys motion by means of a beam I to the rod K of the air-pump L.

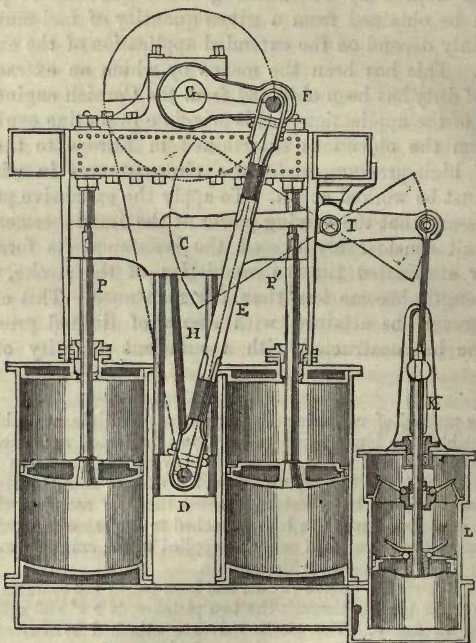
Engines constructed on this principle were applied in several steamers, and amongst others in her Majesty's steam-frigate "Retribution."

49. Within the last ten or fifteen years, and especially since the more general adoption of the screw-propeller, the marine engine has been greatly simplified in its mechanical arrangements. Its bulk has thus been diminished, as well as

the cost of construction; and the profitable tonnage of the vessel has been increased in a corresponding proportion. The beam and its appendages have been very generally laid aside, and the piston-rods have been more directly connected with the cranks.

In some cases the piston-rods are kept in their direction by guides, and their rectilinear motion is accommodated to the

Fig. 9.



rotation of the cranks by connecting-rods, which consequently have an oscillation between the extreme points of the play of the cranks.

In other cases the cylinders themselves receive this oscillation. In such cases the connecting-rods are dispensed with, and the ends of the piston-rods are immediately jointed to the cranks. The oscillation of the piston causes the motion of the valves necessary for the alternate admission and escape of the steam on the one and the other side of the piston.

50. The number of cylinders varies, being generally two, but

sometimes three, sometimes four, and sometimes, though very exceptionally, only one.

The position of the cylinders is subject to great variation. They are placed with their axes sometimes vertical, sometimes horizontal, and sometimes oblique.

51. The proportion of the diameter to the stroke is subject to like variation. The general tendency has been to increase the relative magnitude of the diameter, which in recently built engines is sometimes more than twice the stroke, and rarely less than two-thirds of it. Thus in the engines of the "Niger," constructed by Messrs. Maudslay and Field, the cylinders have 48 inches diameter, with only 22 inches stroke; and in the "Simoom," by Boulton and Watt, they have 44 inches diameter, with 30 inches stroke.

The object of shortening the stroke is to diminish the momentum of the piston, of which the motion requires to be so frequently reversed.

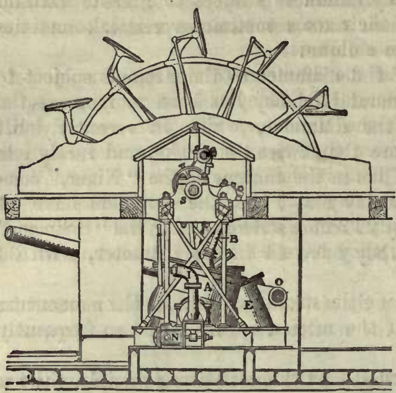
52. In engines constructed on the oscillating principle, the top of the piston-rod is coupled with the crank, and the piston-rod moves backward and forward in the direction of the axis of the cylinder, while its extremity revolves in a circle with the crank. It is therefore necessary that the cylinder should oscillate from side to side, to accommodate the motion of the piston-rod to that of the crank. For this purpose the cylinder is provided on each side with a short hollow pivot or trunnion, on which it swings; and through one of these trunnions the steam enters the cylinder from the boiler, while it escapes through the other to the condenser. The alternate admission and escape of steam on the one side and the other of the piston, is regulated by a valve attached to the cylinder and swinging with it. In the larger class of engines, however, two valves are usually employed for this purpose, and are so arranged as to balance one another.

Oscillating engines are usually placed immediately under the cranks, and occupy no greater length in the vessel than the diameter of the cylinder. On the shaft which connects the engine, called the intermediate shaft, a crank is forged which in its revolutions gives motion to the piston of the air-pump.

53. The arrangements generally employed at present in the most improved vessels propelled by oscillating engines, will be understood by reference to fig. 10, which represents the transverse section of the steam-yacht "Peterhoff," constructed for the Emperor of Russia, by Messrs. Rennie, and fig. 11, which is a side view of the engines of the same vessel. These figures are copied with the permission of the publishers and the authors, from the article on the steam-engine, in the last edition of Brande's "Dictionary of Science." A, A are the cylinders; B, B are the piston-rods, which are connected immediately with the cranks C, C; D is a crank on

the intermediate shaft for working the piston of the air-pump E; F, F are the slide-valves, by which the admission of the steam to the cylinders is regulated; G, G are double eccentrics on the intermediate shaft, whereby the valves F, F are moved; H is a handle, whereby the engines may be stopped, started, or reversed; I, I are the steam-pipes leading to the steam-trunnions K, K, on which, and on other trunnions, connected with the pipe M, the cylinders oscillate; N, N are pumps, the pistons of which are attached to the trunnions, and are worked by the oscillation of the cylinders; O is the waste-water pipe, through which the water which has accomplished the function of condensing the steam is ejected over-board. The same letters refer to the same parts in the two figures.

Fig. 11.

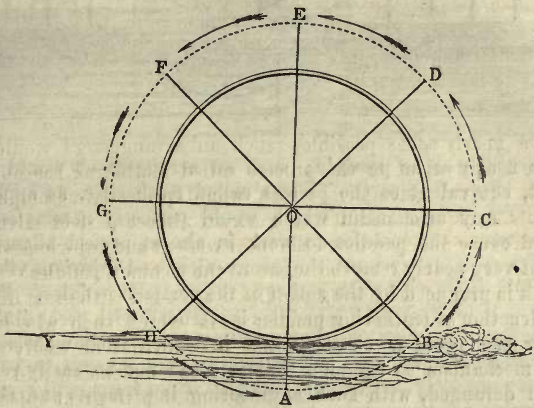


54. To obtain from the moving power its full amount of mechanical effect in propelling the vessel, it would be necessary that it should constantly act against the water in a horizontal direction, and with a motion contrary to the course of the vessel. No system of propellers has, however, yet been contrived capable of perfectly accomplishing this. Patents have been granted for many ingenious mechanical combinations to impart to the propelling surfaces such angles as appeared to the respective contrivers most advantageous. In most of these the mechanical complexity has formed a fatal objection. No part of the machinery of a steam-vessel is so liable to become deranged at sea as the propellers; and, therefore, that simplicity of construction which is compatible with those repairs which are possible on such emergencies is quite essential for safe practical use.

55. The ordinary paddle-wheel, as has been already stated, is a wheel revolving upon a shaft driven by the engine, and carrying upon its circumference a number of flat boards, called paddle-boards, which are secured by nuts and braces in a fixed position; and that position is such that the planes of the paddle-boards diverge from the centre of the shaft on which the wheel turns. The consequence of this arrangement is that each paddle-board can only act in that direction which is most advantageous for the propulsion of the vessel when it arrives at the lowest point of the wheel. In fig. 12, let O be the shaft on which the common paddle-wheel revolves; the positions of the paddle-boards are represented at A, B, C, &c.; X Y represents the water-line, the course of the vessel being supposed to be from X to Y; the arrows represent the direction in which the paddle-wheel

revolves. The wheel is immersed to the depth of the lowest paddle-board, since a less degree of immersion would render a portion of the surface of each paddle-board mechanically useless. In the position A, the whole force of the paddle-board is efficient for propelling the vessel; but as the paddle enters the water in the position H, its action upon the water not being horizontal, is only partially effective for propulsion : a part of the force which drives the paddle is expended in depressing the water, and the remainder in driving it contrary to the course of the vessel, and, therefore,

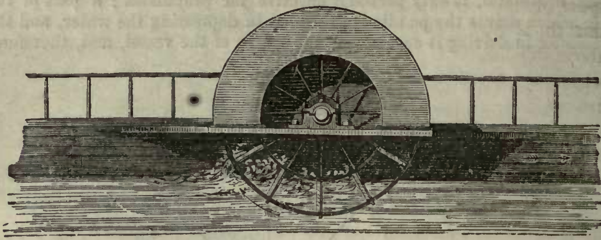
Fig. 12.



by its re-action producing a certain propelling effect. The tendency, however, of the paddle entering the water at H is to form a hollow or trough, which the water, by its ordinary property, has a continual tendency to fill up. After passing the lowest point A, as the paddle approaches the position B, where it emerges from the water, its action again becomes oblique, a part only having a propelling effect, and the remainder having a tendency to raise the water, and throw up a wave and spray behind the paddle-wheel. It is evident that the more deeply the paddle-wheel becomes immersed, the greater will be the proportion of the propelling power thus wasted in elevating and depressing the water; and if the wheel were immersed to its axis, the whole force of the paddle-boards, on entering and leaving the water, would be lost, no part of it having a tendency to propel. If a still deeper immersion take place, the paddle-boards above the axis would have a tendency to retard the course of the vessel. When the vessel is, therefore, in proper trim, the immersion should not exceed nor fall short of the depth of the lowest paddle; but for various reasons it is impossible in practice to maintain this fixed immersion : the agitation of the surface of the sea causing the vessel to roll, will necessarily produce a great variation in the immersion of the paddle-wheels, one becoming frequently immersed to its axle, while the other is raised altogether out of the water. Also the draught of water of the vessel is liable to change, by the variation in the cargo; this will necessarily happen in steamers which take long voyages. At starting they are heavily laden with fuel, which as they proceed is gradually consumed, whereby the vessel is lightened.

56. To remove this defect, and economise as much as possible the propelling effect of the paddle-boards, it would be necessary so to construct them that they may enter and leave the water edgeways,

Fig. 13.



or as nearly so as possible; such an arrangement would be, in effect, equivalent to the process called feathering, as applied to oars. Any mechanism which would perfectly accomplish this would cause the paddles to work in almost perfect silence, and would very nearly remove the inconvenient and injurious vibration which is produced by the action of the common paddles. But the construction of feathering paddles is attended with great difficulty, under the peculiar circumstances in which such wheels work. Any mechanism so complex that it could not be easily repaired when deranged, with such engineering implements and skill as can be obtained at sea, would be attended with great objections.

Feathering paddle-boards must necessarily have a motion independently of the motion of the wheel, since any fixed position which could be given to them, though it might be most favourable to their action in one position, would not be so in their whole course through the water. Thus the paddle-board when at the lowest point should be in a vertical position, or so placed that its plane, if continued upwards, would pass through the axis of the wheel. In other positions, however, as it passes through the water, it should present its upper edge, not towards the axle of the wheel, but towards a point above the highest point of the wheel. The precise point to which the edge of the paddle-board should be directed is capable of mathematical determination. But it will vary according to circumstances, which depend on the motion of the vessel. The progressive motion of the vessel, independently of the wind or current, must obviously be slower than the motion of the paddle-boards round the axle of the wheel; since it is by the difference of these velocities that the re-action of the water is produced, by which the vessel is propelled. The proportion, however, between the progressive speed of the vessel and the rotative speed of the paddle-boards is not fixed; it will vary with the shape and

structure of the vessel, and with its depth of immersion; nevertheless it is upon this proportion that the manner in which the paddle-boards should shift their position must be determined. If the progressive speed of the vessel were nearly equal to the rotative speed of the paddle-boards, the latter should so shift their position that their upper edges should be presented to a point very little above the highest point of the wheel. This is a state of things which could only take place in the case of a steamer of a small draught of water, shallop-shaped, and so constructed as to suffer little resistance from the fluid. On the other hand, the greater the depth of immersion, and the less fine the lines of the vessel, the greater will be the resistance in passing through the water, and the greater will be the proportion which the rotative speed of the paddle-boards will bear to the progressive speed of the vessel. In this latter case the independent motion of the paddle-boards should be such that their edges, while in the water, shall be presented towards a point considerably above the highest point of the paddle-wheel.

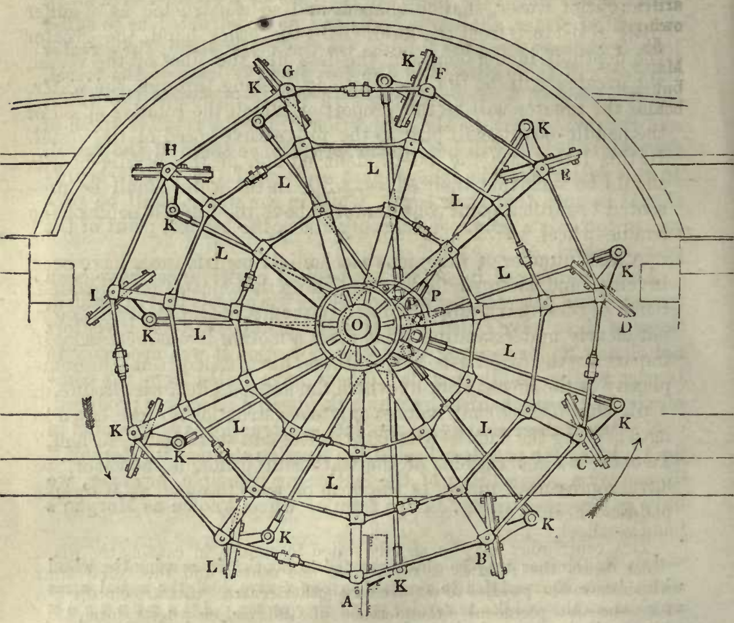
A vast number of ingenious mechanical contrivances have been invented and patented, for accomplishing the objects just explained. Some of these have failed from the circumstance of their inventors not clearly understanding what precise motion it was necessary to impart to the paddle-boards; others have failed from the complexity of the mechanism by which the desired effect was produced.

57. One of these contrivances of late construction is represented in fig. 11, being the paddle-wheel of the Russian steamer "Peterhoff." To convey a general idea of the feathering principle, however, we have represented in fig. 14 the form of wheel known as Morgan's paddle-wheel.

This contrivance may be shortly stated to consist in causing the wheel which bears the paddles to revolve on one centre, and the radial arms which move the paddles to revolve on another centre. Let A B C D E F G H I K L be the polygonal circumference of the paddle-wheel, formed of straight bars, securely connected together at the extremities of the spokes or radii of the wheel which turns on the shaft which is worked by the engine; the centre of this wheel being at O. So far this wheel is similar to the common paddle-wheel; but the paddle-boards are not, as in the common wheel, fixed at A B C, &c., so as to be always directed to the centre O, but are so placed that they are capable of turning on axles which are always horizontal, so that they can take any angle with respect to the water which may be given to them. From the centres, or the line joining the pivots on which these paddle-boards turn, there proceed short arms K, firmly fixed to the paddle-boards at an angle of about 120°. On a motion given to this arm K, it will therefore give a corresponding angular motion to the paddle-board, so as to make it turn on its pivots. At the extremities of the several arms marked K is a pin or pivot, to which the extremities of the radial arms L are severally attached, so that the angle between each radial arm L and the short paddle arm K is capable of being

changed by any motion imparted to L; the radial arms are connected at the other end with a centre, round which they are capable of revolving. Now, since the points A B C, &c., which are the pivots on which the paddle-boards turn, are moved in the circumference of a circle, of which the centre is O, they are always at the same distance from that point, consequently they will continually vary their distance from the other centre P. Thus, when a paddle-board arrives at that point of its revolution at which the centre

Fig. 14.

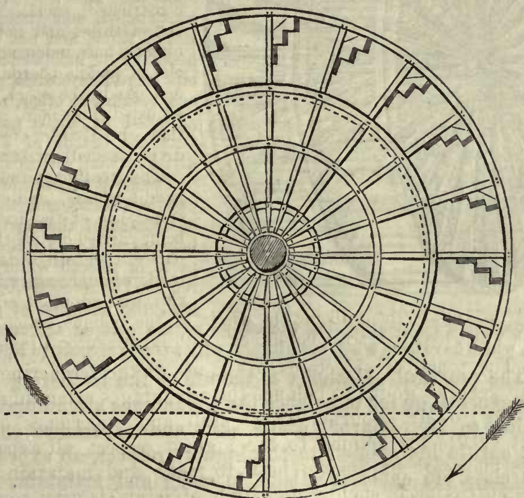


round which it revolves lies precisely between it and the centre O, its distance from the former centre is less than in any other position. As it departs from that point, its distance from that centre gradually increases until it arrives at the opposite point of its revolution, where the centre O is exactly between it and the former centre; then the distance of the paddle-board from the former centre is greatest. This constant change of distance between each paddle-board and the centre P is accommodated by the variation of the angle between the radial arm L and the short paddle-board arm K: as the paddle-board approaches the centre P, this gradually diminishes; and as the distance of the paddle-board increases, the angle is likewise augmented. This change in the magnitude of the angle, which thus accommodates the varying position of the paddle-board with respect to the centre P, will be observed in the figure. The paddle-board D is nearest to P; and it will be observed that the angle contained between L and K is there very acute; at E the angle between L and K increases,

but is still acute; at G it increases to a right angle; at H it becomes obtuse; and at K, where it is most distant from the centre P, it becomes most obtuse. It again diminishes at L, and becomes a right angle between A and B. Now this continual shifting of the direction of the short arm K is necessarily accompanied by an equivalent change of position in the paddle-board to which it is attached; and the position of the second centre P is, or may be, so adjusted that this paddle-board, as it enters the water and emerges from it, shall be such as shall be most advantageous for propelling the vessel, and therefore attended with less of that vibration which arises chiefly from the alternate depression and elevation of the water, owing to the oblique action of the paddle-boards.

58. *Field's split paddles.*—In the year 1833, Mr. Field, of the firm of Maudslay and Field, constructed a paddle-wheel with fixed paddle-boards, but each board being divided into several narrow slips arranged one a little behind the other, as represented in fig. 15. These divided boards he pro-

Fig. 15.



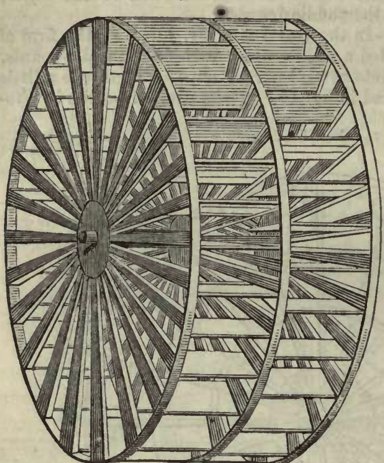
posed to arrange in such cycloidal curves that they must all enter the water at the same place in immediate succession, avoiding the shock produced by the entrance of the common board. These split paddle-boards are as efficient in propelling when at the lowest point as the common paddle-boards, and, when they emerge, the water escapes simultaneously from each narrow board, and is not thrown up, as is the case with common paddle-boards.

The number of bars, or separate parts into which each paddle-board is divided, has been very various. When first introduced, each board was divided into six or seven parts: this was subsequently reduced; and in the wheels of this form constructed for the government vessels, the paddle-boards consist only of two parts, coming as near to the common wheel

as is possible, without altogether abandoning the principle of the split paddle.

59. The paddle-wheels generally used in American steam-boats are formed, as if by the combination of two or more common paddle-wheels, placed one outside the other, on the same axle, but so that the paddle-boards of each may have an intermediate position between those of the adjacent one, as represented in fig. 16.

Fig. 16.



The spokes, which are bolted to cast-iron flanges, are of wood. These flanges, to which they are so bolted, are keyed upon the paddle-shaft. The outer extremities of the spokes are attached to circular bands or hoops of iron, surrounding the wheel; and the paddle-boards, which are formed of hard wood, are bolted to the spokes. The wheels, thus constructed, sometimes consist of three, and not unfrequently four, independent circles of paddle-boards, placed one beside the other, and so adjusted in their position, that the boards of no two divisions shall correspond.

The great magnitude of the paddle-wheels, and the circumstance of the navigation being carried on, for the most part, in smooth water, have rendered unnecessary, in America, the adoption of any of those expedients for neutralising the effects of the oblique action of the paddles, which have been tried, but hitherto with so little success, in Europe.*

60. The practical objections to the use of the feathering principle in general, go far to balance the advantages attending them. According to Mr. Bourne, whose skill and experience on this subject entitle his opinion to the highest respect, all expedients of this class are expensive, both to make and maintain. The wear and friction in such a multitude of joints is very considerable; and if any of the arms get adrift, or break, they will be whirled round like a flail, and may perhaps cut through the paddle-box, or even the vessel. If the injury be of such a nature that the wheels cannot be turned round (and this has sometimes happened), it will follow that the engines will be virtually disabled until the obstruction can be cleared away; and if the weather be very stormy, or the vessel be in a critical situation,

* For a notice of the inland steam navigation of the United States, see "Railway Economy," chap. xvi. Also "Museum of Science and Art," vol. ii. p. 17.

she may be lost in consequence of her temporary derangement. Upon the whole, therefore, the application of feathering wheels to vessels intended to perform long voyages through stormy seas, appears to be of doubtful propriety. For channel trips, and in situations where the wheels can be carefully examined at short intervals, the risk is not so great; but in that case nearly the same benefits will be attained by increasing the length of the paddle-floats, and giving the wheels less dip. There is no material difference between the performance of a feathering wheel and that of a radial wheel, if the two wheels be of the same diameter, and if they have both a light dip with long narrow floats. And, as in sea-going vessels, the wheels must necessarily be of considerable diameter, and as there is nothing to prevent the other circumstances conducive to efficiency from being observed, it follows that in ocean-vessels radial wheels would be about as efficient as feathering wheels, but for the circumstance of a variable immersion. It is not necessary, however, that there should be much variation in the immersion if large vessels be employed, or if coal is more frequently taken on board during the voyage; and as neither of these alternatives is attended with the risk incident to the use of feathering wheels, they appear to be entitled to that preference which ultimately they are likely to obtain.

61. In oscillating engines the piston-rod is usually made one-ninth of the diameter of the cylinder, and the crank-pin is made about one-seventh of the diameter of the cylinder. The diameter of the paddle-shaft must have reference not merely to the diameter of the cylinder, but also to the length of the stroke of the piston, or, what is the same thing, to the length of the crank. If the square of the diameter of the cylinder in inches be multiplied by the length of the crank in inches, and the cube-root of the product be extracted, then that root multiplied by ·242 will give the diameter proper for the shaft in inches at the smallest part. The diameter of the trunnions is regulated by the diameter of the steam and eduction pipes, and these are each usually about one-fifth of the diameter of the cylinder; but it is better to make the steam trunnions a little less, and the eduction trunnions a little more, than this proportion. The steam and eduction pipes, where they enter their respective trunnions, are kept tight by a packing of hemp, which is compressed by a suitable ring or gland, tightened by screws. In land engines the air-pump and condenser are each made about one-eighth of the capacity of the cylinder, but in marine engines they are made somewhat larger.

62. Submerged propellers, whatever be their form, are exempt from many of the disadvantages which are common to every species of paddle-wheel. It will be evident that the effect of

such a propeller will be nearly the same, whatever position may be given to it in the water. However the ship may pitch or roll, or however unequal the surface of the sea may be, such a propeller will always produce the same backward current without any variation of effect.

The circumstances which prevent the co-operation of the power of steam with that of the sails in steam-vessels propelled by the common paddle-wheels, will not operate with submerged propellers, inasmuch as their effect is altogether independent of the careening of the ship.

63. But though this defect is remedied, the submerged propellers in general are still subject to objections, to which even the common paddle-wheel is not obnoxious. Being permanently submerged and liable to accident, fracture, and derangement from various causes, they are inaccessible, and cannot be repaired at sea. But, besides this, when the object in view is to take full advantage of the power of the sails at times when it is expedient to suspend the action of the machinery, the submerged propeller becomes an obstruction, more or less considerable, to the progress of the vessel. Various expedients have been contrived, and in some instances practically applied, by which the propeller can be lifted out of the water when it is not in operation, but hitherto this has not been found practically convenient, at least for commercial vessels, though sometimes adopted for vessels of war.

64. The screw-propeller is similar in form and mechanical principle to the hydraulic machine known as the screw of Archimedes. A cylinder placed at the bottom of the vessel, and in the direction of the keel, is surrounded by a spiral blade similar, precisely, to the thread of a common screw, but projecting from it instead of being cut into its surface. If such a screw were turned in a solid, it would move forward through a space equal to the distance between two contiguous threads in each revolution; but the water, not being solid, yields more or less to the re-action of the screw, and consequently the screw moves forward through a space in each revolution less than the distance between two contiguous threads.

65. The distance between two contiguous threads is technically called the *pitch* of the screw; a term, however, which is sometimes also used to express the angle formed by the blade of the screw with its axis, such angle supplying the means of calculating the distance between such contiguous threads. We shall here, however, use the term pitch in the former sense. The difference between the pitch of the screw and the space through which the screw actually progresses in the water in one revolution is called the *slip*.

In the first vessels to which screw-propellers were applied, the screw consisted of a single spiral blade, which made one convo-

lution only round the cylinder. This arrangement was subsequently modified, and two convolutions and a half of a double-threaded screw were used instead of one complete convolution of a single-threaded screw. This plan has been occasionally varied, a smaller fraction of a convolution being sometimes used.

It is found in practice that the amount of the slip in general varies from one-tenth to one-twentieth of the pitch; that is to say, the actual velocity of the screw through the water is from one-tenth to one-twentieth less than it would be if the screw worked through a solid, or as an ordinary screw in its nut.

66. The screw-propeller is usually fixed upon an axis parallel to the keel of the vessel, and mounted in a space in the dead wood between the stern-post and rudder-post. It is usually suspended on a short shaft, carried by a metal frame, having a rack on each side, in which endless screws work, by means of which the frame supporting the propeller can be lifted out of the water, so that the screw can be repaired if required or a new one introduced without putting the vessel into dock.

To enable the water to react in a manner analogous to that in which the nut reacts upon the common screw, the thread requires to be much deeper than if the screw worked in metal or wood, and the pressing surface to be proportionally larger. Accordingly screw-propellers are always made with much smaller central bodies, and a much deeper thread than the common screw. They are also made as large as possible in diameter, extending generally from the keel to a point nearly level with the surface of the water. Thus the diameter of the screw is little less than the draft of the vessel.

67. To convey some idea of the forms of screw-propellers, we have represented in the annexed figures the forms of some of the propellers most generally adopted.

In fig. 17 is represented a perspective view of Smith's screw-propeller, with two threads or blades, as finally adopted in her Majesty's steamer

Fig. 17.

Fig. 18.

Fig. 19.

Fig. 20.

"Rattler." This is the form of the screw now most generally adopted in the

British navy. An end view or an elevation looking against the end of the shaft is shown in fig. 18. Smith's three-thread screw differs from this only in having three arms instead of two.

Fig. 21.

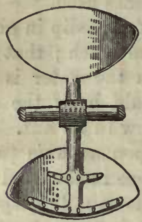


Fig. 22.

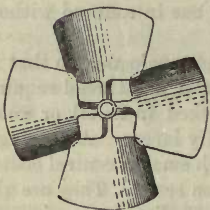
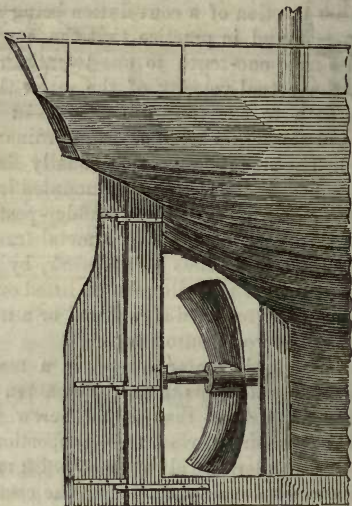


Fig. 23.



Strimman's propeller is shown by an end view in fig. 19, and a side view in fig. 20.

Sunderland's propeller, as applied in the "Rattler," is shown in fig. 21, consisting of two flat plates, set upon arms, fixed to an axis revolving beneath the water in the stern. In the "Rattler," this propeller was placed in the stern in the dead wood, instead of projecting out behind the rudder as in the Sunderland arrangement.

In fig. 22 is represented Woodcroft's propeller, also applied in the "Rattler." This has four arms or blades, and the pitch of the screw at its leading edge is less than the pitch at its terminal edge.

In fig. 23 * is represented, as set in the stern of the vessel, the form of Hodson's screw, from which excellent results are said to have been obtained. This form of screw has been much used in France, Holland, and other countries of the continent; and in some cases in which the common screw has been superseded by a screw of this description, an improvement has been obtained in the speed amounting to about a knot an hour. Such results will only ensue when the original screw has been of inadequate dimension, so that the loss by slip has been large in amount, and the more the slip is reduced, the less will become the advantage of any deviation from Smith's form of screw with uniform pitch.†

* Figs. 17 to 23 have been taken with the permission of the author from Mr. Bourne's work "on the Screw-propeller."

† Bourne "on the Screw-propeller," p. 136.

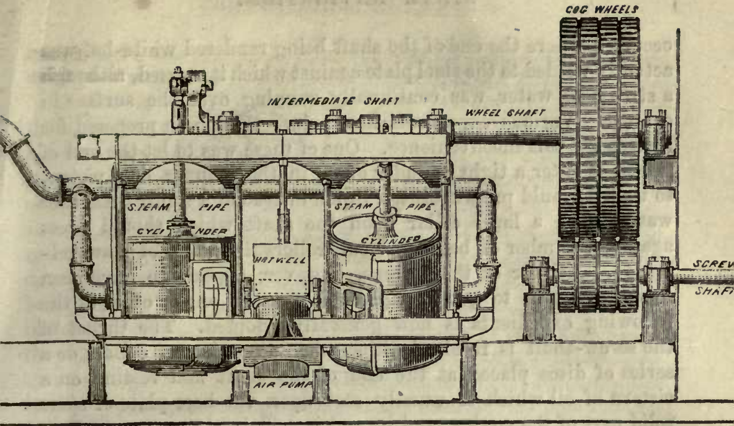


Fig. 26.

STEAM NAVIGATION.

CHAPTER IV.

68. Effect of the screw-propeller reaction on the vessel.—69. Their best practical proportion.—70. Their varying pitch.—71. Relative advantages of screw and paddle-wheels.—72. Their effects in long sea-voyages.—73. Experiments with the "Rattler" and "Alecto."—74. These experiments continued.—75. Admiralty experiments.—76. Government report.—77. Application of the screw in the commercial marine.—78. Application of screw to mail-vessels.—79. Geared and direct action.—80. Geared-engines.—81. Fairbairn's internal gearing.—82. Subdivision of the power among several cylinders.—83. Protection from shot.—84. Regulation of slides.—85. Relative speed of screw and vessel.—86. Engines of the "Great Britain."—87. Engines of the "Arrogant" and "Encounter."—88. Various forms of screw-engines.—89. Cross action of H. M.'s screw steam-packet "Plumper."—90. Auxiliary steam-power.—91. Effect of screw-vessels head to wind.—92. Nominal and real horse-power.—93. Official tables of the strength of the steam-navy.

68. The screw, whatever be its form or structure, in driving the water sternwards, sustains a corresponding reaction which takes effect upon the screw-shaft, and produces an equivalent pressure on its bearing to its anterior extremity. The force of this forward thrust of the screw-shaft, combined with its velocity of rotation, produced, in the earlier screw-vessels, considerable inconvenience in consequence of the friction attending it, and several cases

occurred where the end of the shaft being rendered white-hot was actually welded to the steel plate against which it pressed, although a stream of water was continually running over the surface in contact. Various expedients have since then been proposed for remedying this inconvenience. One of these was to let the end of the shaft enter a tight cylinder of oil in the manner of a piston, so that it would press against a liquid instead of a solid. Another was to place a large collar upon the shaft which should press against a number of balls or small rollers like those of a swivel-bridge. Neither of these plans, however, appears to have been so successful as to get into general use, and one or other of the following expedients is now generally adopted. The thrust of the screw-shaft is received either upon a number of collars or a series of discs placed at the end of the shaft and resting on a cistern of oil which is usually cast upon the base plate or some solid part of the engine, and its end is sufficiently strong to bear the thrust of the screw. Interposed, however, between the end of the cistern and that of the shaft are two, three, or more discs of metal, generally two inches thick, and having diameters equal to that of the shaft. A bolt passes through their centre to keep them in line, but they are each free to revolve in the bolt, and where the shaft passes out of the cistern a collar of leather is applied to prevent the oil from escaping. It will be obvious from such an arrangement that if the end of the shaft which it presses upon the discs begins to heat from undue friction, it will revolve with somewhat more difficulty, and will consequently carry the first disc round with it. The rubbing surfaces are therefore no longer at the end of the shaft, but at the first disc and the second disc. In fact the rubbing surfaces, instead of being limited to a single disc, are distributed over several. Those surfaces which begin to heat, and consequently to stick, will cease to rub, whereby they will speedily become cool again and their efficiency consequently be restored. (See Mr. Bourne's article on the "Screw-Propeller" in the Appendix to Brande's "Dictionary of Science and Art.")

69. According to the same authority the best practical proportion and form of screw-propellers for mercantile vessels are as follows. Those of three blades are on the whole preferable. The diameter should be as large as possible. When the area of the circle described by the extremity of the arms of the screw has one square foot for every two-and-a-half square feet in the area of the midship section immersed, a very efficient performance is obtained. The pitch of the screw should be equal to its diameter, or perhaps a little exceed it, and the length measured parallel to its shaft should be about one-sixth of a convolution. Thus, for

example, in the case of a screw 12 feet in diameter, the pitch would be from 12 to 14 feet, and the length about 2 feet.

70. Screws are generally made with one uniform pitch, and their blades are set at right angles to the shaft. A gradual increase of pitch towards the leading end of the screw is, however, recommended. Thus, the pitch of the centre should be about 10 per cent. less than at the circumference, for the centre should merely screw through the water, without producing any reaction or propelling force. The efficient part being near the circumference, it is also recommended that the blades, instead of being precisely perpendicular to the shaft, should be inclined a little sternwards, so as to produce a tendency in the water which they drive backwards to converge to a point. It is assumed that this convergent tendency may balance the divergent tendency due to the centrifugal force attending the revolution: so that the two forces being in equilibrium will cause the water to be projected backwards from the screw in a cylindrical column. In the case of the ordinary screw, with blades at right angles to the shaft, the water projected backwards assumes the figure of the frustum of a cone, and a certain proportion of the power is thereby lost.

71. The relative advantages of screw and paddle-propellers depend in a great degree upon the immersion. It appeared from experiments made on a considerable scale with steamers of the Royal Navy, that in deep immersion the screw has an advantage over the paddle-wheel of one-and-a-half per cent.; but that, with medium immersion, the paddle-wheel had an advantage of one-and-three-quarters per cent. over the screw, an advantage which was augmented to four-and-three-quarters per cent. for light immersions. It appears, therefore, that the screw-propeller has a certain advantage over the paddle when the vessel is deep in the water, and that, on the other hand, the paddle gains an advantage over the screw in proportion as the immersion is less.

72. In long sea voyages, where the immersion is liable to considerable variation by reason of the lightening of the vessel owing to the consumption of the fuel, the screw will have the advantage over the paddle in the commencement of the voyage, and the paddle over the screw towards the end of it. In rough weather, where, by the rolling and pitching of the vessel, the paddle-wheels are liable at one time to be deeply plunged in the water, and at another to be raised out of it, the screw will have an obvious advantage.

73. In his work upon the screw-propeller, Mr. Bourne has given the details of a series of important experiments made with H. M. steamers "Rattler" and "Alecto," to determine the relative advantages of screw and paddle-wheels against a head wind. The result of these experiments seemed to prove, that

under such conditions the screw is less efficient than the paddle; for though both vessels attained the same speed of four knots against a strong head wind, yet, in the case of the "Alecto," this performance was attained with a velocity of the engine of 12 strokes per minute, whereas in the "Rattler" it was only attained with a velocity of the engine of 22 strokes per minute. It follows, therefore, that a screw-vessel in proceeding head to wind will require 1·8 times, or nearly twice the quantity of fuel to do the same amount of work. The screw, in fact, revolves at nearly the same velocity whether the wind is adverse or favourable, or whether the vessel is lying at anchor; and this is a serious defect in the case of vessels intended to encounter adverse winds. In the case of vessels, however, which use the screw only as a resource in calms, or as an auxiliary to the sails, this disadvantage will not be experienced, since such vessels have no pretensions to the capability of proceeding in direct opposition to a strong head wind.

74. Among the experiments made with the "Alecto" and "Rattler," some of the most interesting and important were directed to the determination of the relative towing powers of the screw and paddle-wheel. For this purpose the two ships were lashed stern to stern, and the engines of both were set to work so as to make them draw the connecting chain in opposite directions. In these and all other cases where screw and paddle-vessels of equal power and size have been thus connected, the screw-vessel has preponderated, and towed the paddle-vessel as soon as the engines were set to work.

When the "Rattler" and "Alecto" were lashed together in this manner, the "Alecto's" engines were set on first, and she was allowed to tow the "Rattler" at the rate of two knots an hour. The "Rattler's" engines were then set on. In five minutes the two vessels became completely stationary. The "Rattler" then began to move ahead, and towed the "Alecto" against the whole force of her engines, at the rate of 2·8 knots per hour. In like manner the "Niger" towed the "Basilisk" astern, in opposition to the force of her engines at the rate of 1·1 knots per hour. The natural inference from this experiment would be that the screw is more suitable for towing than the paddle; yet this inference is not confirmed by the experiment, for when the "Niger" and "Basilisk" were each set to tow the other alternately, in the usual manner in which a steamer tows a ship, it was found that the "Niger" towed the "Basilisk" at a speed of 5·63 knots, with 593·9 horse-power, and that the "Basilisk" towed the "Niger" at the rate of 6 knots, with 572·3 horse-power. The paddle-vessel, therefore, accomplished in towing the largest speed with the least power. It has also been found that when a paddle

and screw-vessel set stern to stern push one another instead of pulling one another, the paddle-vessel preponderates, whereas, if they pull, the screw-vessel preponderates. These circumstances seem to show that the power of a screw-vessel to tow a paddle-vessel astern, when the two are tied together, does not arise from any superior tractive efficacy of the screw itself, but is due to the centrifugal action of the screw, which raises the level of the water at the stern, so that the vessel gravitates down an inclined plane.*

75. The first experiments tried by the Admiralty with the screw-propeller were made in 1840-41; and in the next three years, 1842-44, eight screw vessels were built. This number was augmented by twenty-six in 1845. In 1848 there were not less than forty-five government screw-steamers afloat; and since that time, and more especially since the commencement of the war with Russia, the increase of the screw-steam navy has gone on at a rate which justifies the conclusion that ere long no vessel of war, of whatever class, in the British navy will be unprovided with the power, to a greater or less extent, of steam propulsion.

76. In a government official report of the results of various trials of the performance of screw-steamers, dated so far back as May 1850, before that propeller had yet reached its present state of perfection, it is stated as then highly probable that fine sailing vessels, fitted with auxiliary screw-power, would be found able, if not to rival, at least to approach, full-powered and expansively acting steam-ships, in respect of their capability of making a long voyage with certainty and in a reasonably short time.

"Another application of the screw, although inferior in general importance to its application as a propeller to ordinary ships," says the same report, "is certainly deserving of more attention than is commonly paid to it, namely, as a manœuvrer to those large ships in which engines of considerable power cannot be placed, or in which it is considered unadvisable to place them. No doubt can be entertained of the efficiency of such an instrument worked by an engine of even fifty horse-power. The full extent, however, of its utility cannot perhaps be thoroughly appreciated until it shall have been extensively used in her Majesty's navy."

Since the date of this report that experience which was wanted has been obtained, and the extensive use of the screw has been adopted, and the results fully confirm all those anticipations.

77. But it is not only in her Majesty's navy, but in the national commercial marine, and not only as an auxiliary propeller, but as an independent and most efficient agent of propulsion, that the screw has been found to answer in practical navigation. In 1849,

* Bourne "on the Screw-propeller," Chap. IV.

before it had yet attained all its present degree of perfection, it was in extensive operation under the direction of the General Screw Shipping Company. Seven vessels belonging to that company were in operation during the twelve months ending 31st December, 1849, during which time they performed 170 voyages, being an average of about 24½ voyages per vessel. The total distance run was 110849 geographical miles, being at the average rate of 15835 miles per vessel, and about 648 miles per voyage. The average speed was 8 to 8½ geographical miles per hour, and only one casualty, and that one in the Thames, occurred during the year.

The speed of the best and most recent of these vessels in still water, running the measured mile in the long reach of the Thames, was found to be 9·68 knots per hour.

78. Practical authorities have suggested, that the greatly increased and rapidly increasing number of screw ships running between the British and American ports, suggests the expediency of a revision of the post-office contracts, with a view to public economy, without any real sacrifice of efficiency. It is considered that no difference of time worthy of consideration now prevails between the passages of the mail-packets and the screw-vessels; but even admitting a difference, it is certainly not so great as that which exists between the speed of the mail and that of the express trains on railways. If then the mail contracts on the iron lines are sufficiently well performed by the trains of second-rate speed, why may not the like contracts on the lines of water be similarly executed, where the difference of cost would be enormous, and the difference of speed comparatively insignificant.

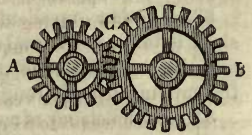
It is obvious that these observations are applicable not only to the lines of steamers which carry the United States and Canadian, but also to the West Indian, and in a word, to all the ocean lines.

79. But when screw propulsion is used, a much greater velocity of revolution is required to be given to the screw-shaft,—a much greater number of revolutions per minute being necessary, than the greatest number of strokes per minute made by any steam-engine of the common construction. It was necessary, therefore, in adopting screw propulsion, either to provide expedients by which the velocity of rotation of the screw-shaft shall be greater than that of the crank-shaft, in the requisite proportion, or to modify the form and proportions of the steam cylinders and their appendages, so that the number of strokes per minute should be augmented, so as to be equal to the necessary number of revolutions per minute of the screw-shaft.

Both these contrivances have been adopted by different constructors. Engines constructed on the former plan are called *geared engines*, and those constructed on the latter *direct acting engines*.

80. In geared engines the cranks are formed on one shaft, and the screw fixed upon another, the directions of the two shafts being parallel. On the crank-shaft is fixed a toothed-wheel, which works in a smaller one, called a pinion, fixed on the screw-shaft. Thus in fig. 24, A may be regarded as the pinion fixed on the screw-shaft, and B the wheel fixed on the crank-shaft, the teeth of the one being engaged in those of the other at C.

Fig. 24.



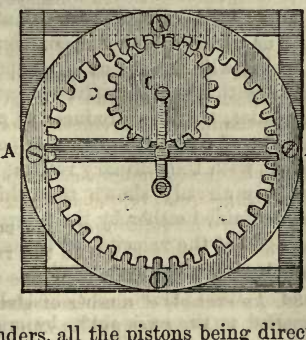
It is evident that the velocity of rotation of A will be greater than that of C in the same proportion as that in which the number of teeth in C is greater than the number of teeth in A. It is always possible, therefore, with a given speed of the crank-shaft, to impart a speed greater in any required proportion to the screw-shaft by regulating in a corresponding manner the proportion of the teeth in those geared wheels.

81. One of the objections to the use of gearing in sea-going vessels is the liability of the teeth to rapid wear, and to fracture from sudden shocks in a rough sea. In order to diminish the risk of this by distributing the pressure over a greater number of teeth, Mr. Fairbairn has adopted in large screw-engines, constructed by him for the Royal Navy, a system of internal gearing in which the crank-shaft wheel has the teeth on its internal periphery, the screw-shaft pinion revolving within it, as shown in fig. 25.

In screw-vessels of war, all the machinery should be placed below the water-line, so as to be as effectually protected from shot as the screw itself is.

82. When direct-acting engines without gearing are applied to screw-propelled vessels, the reciprocating motion of the piston must be equal to the velocity of the screw, that is, the number of strokes per minute of the piston must be equal to the number of revolutions per minute of the screw. Now to render this compatible with a sufficiently moderate rectilinear motion of the piston, the length of the stroke must bear a very small proportion to the diameter of the cylinder. This has, in many cases, rendered it necessary in such vessels to subdivide the power of the engines among four smaller cylinders, all the pistons being directly attached to cranks on the screw-shaft instead of producing it by two larger cylinders, in which an unmanageable proportion must be adopted between the diameter and the stroke.

Fig. 25.



Another advantage derived from this subdivision of power is, that

a number of small cylinders, ranged often in a horizontal position on either side of the screw-shaft, allow of the play of all the reciprocating parts within a small height, so as to keep the whole below the water-line.

83. Another expedient for the protection of the machinery from shot, is to place the coal-boxes on each side of it, and between it and the timbers of the vessel, so that before a shot could reach it, the fuel must be thoroughly penetrated.

84. The efficiency of a marine, like that of a land engine, depends on the exact regulation of the slides by which the admission and escape of the steam to and from the cylinder is governed. In all cases the steam should be admitted at either end of the cylinder a little before the arrival of the piston there, and at the same moment the escape to the condenser should be stopped. By this means the piston, on arriving at the end of the stroke, is received by the steam just admitted mixed with a small portion of uncondensed steam and air, whose escape to the condenser has been intercepted. These form a sort of air-cushion, against which the stroke of the piston is broken, an effect which is called by the practical men, not inappropriately, *cushioning* the piston. When the steam is worked expansively, the slides must be capable of such regulation as to shut it off at any required fraction of the entire stroke, and when not so worked, it ought at all events to be shut off before the stroke is quite completed, so as to relieve the piston from its action a little before the termination of the stroke.

It is easy to conceive that, to accomplish all these points, the slides require the nicest imaginable adjustment; and the openings for the admission and escape of steam, the most exact regulation both as to magnitude and position.

85. It will be evident on comparing the pitch of the ordinary screw with the progressive rate at which the vessel moves through the water, that, to produce the necessary speed, a much greater velocity of rotation must be imparted to the screw, than is consistent with the ordinary rate at which steam-engines work. It has been already shown that this great velocity of rotation has been obtained either by the interposition of gearing so adapted as to augment the velocity, or by assimilating the engine in its form and structure to a locomotive.

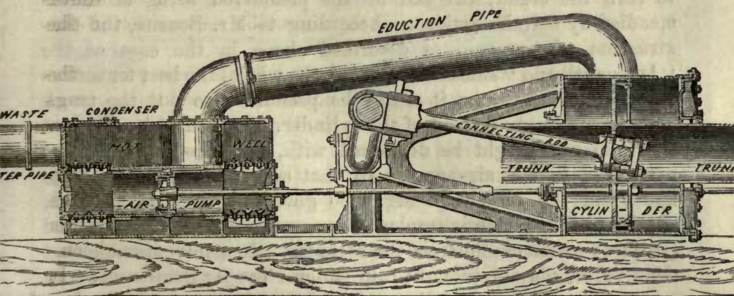
86. An example of a marine-engine, by which the necessary velocity is imparted to the screw-shaft, by means of intermediate gearing, is presented in the case of the screw-engine constructed by Messrs. Penn and Son, for the "Great Britain" steam-ship. The engines which are represented in fig. 26, are constructed on the oscillating principle, and are almost identical with the paddle-wheel engines, built by the same firm for the "Sphinx."

The "Great Britain" is a vessel of 3500 measured tons; her tonnage by deplacement being 2970, and her draught 16 feet. The diameter of the cylinder is $82\frac{1}{2}$ inches; the length of stroke, 6 feet; the nominal power, 500 horses; the diameter of the screw, $15\frac{1}{2}$ feet; its pitch, 19 feet, and its length, 3 feet 2 inches. The screw has three arms or blades, and its shaft is connected with the crank-shaft by a pair of toothed-wheels, which have a multiplying power of 3 to 1, so that for every stroke of the piston, the screw-shaft revolves three times. The ample proportion of $17\frac{1}{2}$ square feet of heating surface per nominal horse-power, is provided in the boiler.

The crank-shaft, being put in motion by the engine, carries round the great cog-wheel, or combination of cog-wheels, which are fixed upon it; and this wheel acting on smaller ones called pinions, on the screw-shaft, impart to the latter the threefold velocity of revolution just mentioned.

87. As an example of screw-propelling engines working without gearing, we give in fig. 27 those constructed by Messrs. Penn and Son for H. M.'s screw-steamers "Arrogant" and "Encounter." In this case the cylinders are horizontal, and are traversed through the centre by a pipe or trunk, upon which the piston is cast. This trunk is projected through both ends of the cylinder—the orifices through which it passes being rendered steam-tight by proper packing. One end of the connecting-rod is attached to the centre of the trunk, the other end being connected with the crank, which is formed directly upon the screw-shaft. The air-pump lies in a horizontal position, is double-acting, and placed within the condenser. A large pipe, called the eduction pipe, leads from the cylinder to the condenser, where the condensation is produced by a jet of cold water, and the warm water resulting from the process is ejected by the air-pump through the waste-pipe, and discharged overboard. In fig. 27 one cylinder and one air-

Fig. 27.



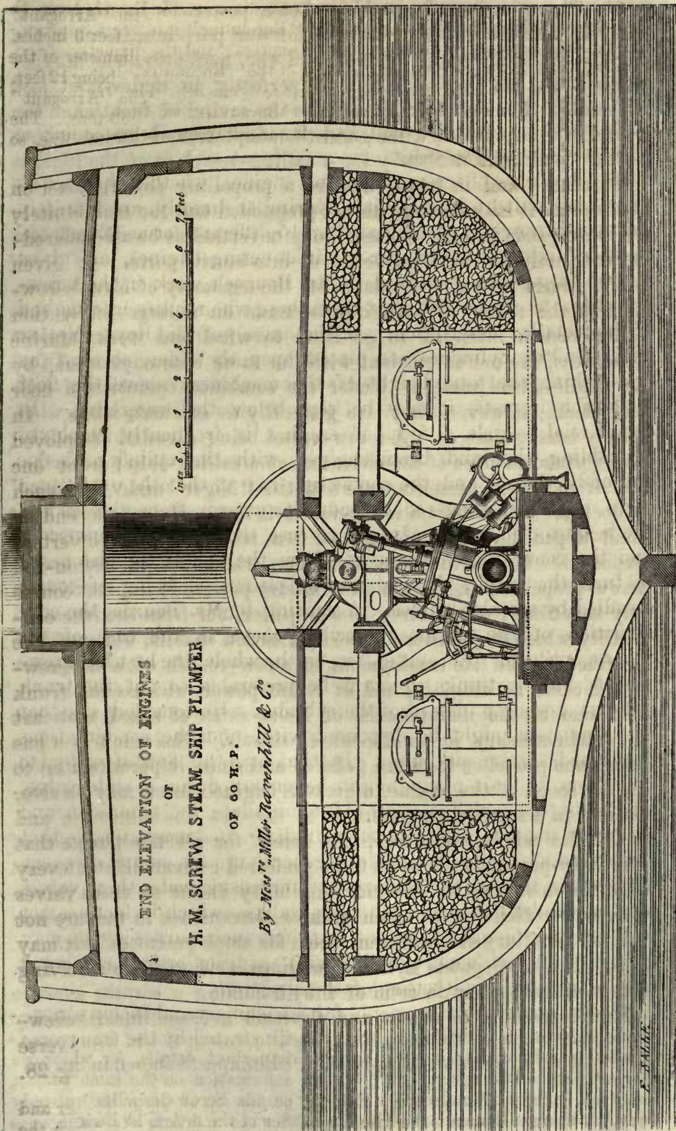
pump only are represented, but it must be understood that there are two, precisely similar to each other, placed side by side. The valves by which the water is admitted to the air-pump from the condenser, and those by which it passes from the air-pump to the hot well and waste-pipe, consist of several discs of caoutchouc kept down by a central bolt, so as to cover radial slits or orifices in a perforated plate. These valves are found to operate without noise or shock, notwithstanding the high speed at which the engine must work, in order to give the necessary velocity to the screw-shaft without intervening gearing. The diameter of the cylinder of the "Arrogant" and "Encounter" is 60 inches, and the diameter of the trunk 24 inches; the latter being deducted from the former, leaves an effective

piston area equal to that of a piston 55 inches in diameter. In the "Arrogant" the length of stroke is 3 feet, and in the "Encounter" it is 2 feet 3 inches. The nominal power of both engines is 360 horses; and the diameter of the "Arrogant's" screw is 15 feet 6 inches, that of the "Encounter" being 12 feet. The pitch of both is 15 feet, and the length 2 feet 6 inches. The "Arrogant" is a vessel of 1872 tons burden, and the "Encounter" of 953 tons. The whole machinery, including the boilers, is placed below the water line, so as to be protected from shot.*

88. The forms of screw-propelling engines, whether they act on the screw-shaft by intermediate gearing or directly, are infinitely various. Drawings of not less than 15 different forms of geared-engines, and the like number of direct acting engines, are given in two large plates prefixed to Mr. Bourne's work on the screw-propeller, to which we must refer those who require information of this detailed description. In the vessels of the Royal Marine generally the cylinders are placed upon the sides, so that, by diminishing the total height of the machinery above the floor on which it rests, it may be kept below the water-line. In commercial vessels a form of engines is frequently employed resembling the land beam-engines, with the cylinder at one end of the beam, and the connecting-rod at the other. In such cases the connecting-rod extends downwards from the end of the beam to the crank. In either case the cylinder is inverted, and the connecting-rod proceeds from the end of the piston-rod to turn the crank, the end of the piston-rod being of course steadied by suitable guides. According to Mr. Bourne, the construction of the engines described above in the case of the "Arrogant" and "Encounter" is, on the whole, the best for screw-vessels, but he thinks it might be preferable to put the trunk into the air-pump instead of the cylinder. He considers also that the condenser might be dispensed with, and the condensations performed in the air-pump. In that case the flow of water to and from the air-pump might be governed by a slide-valve, similar to that which is employed to regulate the admission and escape of steam to and from the cylinder. It seems probable that slide-valves may be brought into general use for pumps of every sort, but in the case of ordinary ones for raising water these valves need not be like the common slide-valves, which in fact are not well adapted to give sufficient area for such purposes, but may consist of a short wide cylinder with gridiron orifices revolving slowly at the top and bottom of the air-pump.

89. The general arrangement of the machinery and fuel in screw-propelled vessels of the Royal Navy is illustrated by the transverse section of H.M.'s screw steam-packet "Plumper," shown in fig. 28.

* Figs. 26 and 27 are copied, with the permission of the publisher and the author, from Brande's "Dictionary of Science and Art," to which the


END ELEVATION OF ENGINES
OF
H. M. SCREW STEAM SHIP PLUMPER
OF 60 H. P.
By Messrs. Miller Ravenhill & Co.
7 Feet

90. The question of auxiliary steam power to be used occasionally, as well for commercial as for war purposes, is one of the highest importance and interest, and one, moreover, which experience has not yet enabled us perfectly to understand and elucidate. For commercial purposes the saving of fuel, when the vessel has favourable winds, and the adaptation of her structure to the conditions necessary for a sailing-vessel, is of the highest importance; and in naval warfare a propelling power, however inadequate it may be for constant propulsion and the maintenance of high speeds in long voyages, may nevertheless be all-sufficient for conducting vessels into action or into hostile ports.

91. It has been already stated on the authority of Mr. Bourne, and as the result of experiments made on a large scale, that screw-vessels intended to go head to wind and work against head-seas, are not as efficient with the same consumption of fuel as paddle-wheel vessels. Under the combined operation of sails and steam, however, they are generally as efficient, and, when deeply laden, more so. A screw-vessel being divested of paddle-boxes partakes more of the character of a sailing-ship; nevertheless, from the experiments made with the "Niger" and "Basilisk," it does not appear that a screw-vessel is more efficient under sails than a paddle-vessel, though such a result may naturally be expected. The advantages, therefore, which attend the use of screw-propelling engines as an auxiliary power, do not result from any superiority of the screw as a propeller, nor from the increased facility which it presents for the application of sails, but are to be ascribed to the late employment in screw-vessels of wind-power which costs nothing, instead of steam-power which costs much, and also to the maintenance of lower rates of speed than are thought necessary in paddle-wheel vessels. The screw is a less cumbrous propeller than the paddle, and since it permits a much higher speed of the engine, a greater engine power may be compressed in a smaller compass.

On the whole, therefore, the screw for all the purposes of auxiliary propulsion is much to be preferred; nevertheless it must be understood that its superior eligibility is not so much due to its greater efficiency, as to the greater convenience in the application of auxiliary steam-power which its employment affords.

92. The horse-power of marine engines is either nominal or real. The nominal power is estimated by assuming a certain average effective pressure of steam, and a certain average linear velocity

reader is referred for a great mass of important details, for which we cannot here afford space. Still further information on the same subject may be found in Mr. Bourne's work "on the Screw-propeller" already quoted, that gentleman being also the author of the article in Brande.

of the piston. The pressure multiplied by the velocity gives the effective force of the piston, or, what is the same, of the engine exerted through a given number of feet per minute; and since the force called a horse-power means 33000 lbs. acting thus one foot per minute, it follows that the nominal power of the engine will be found by dividing the effective force exerted by the piston, multiplied by the number of feet per minute through which it acts, by 33000.

It is assumed in all Admiralty contracts, and generally also in those of the commercial marine, that, after deducting from the total pressure of steam in the boiler that portion which is neutralised by the gases and uncondensed steam in the condenser, the friction of the moving parts and all other sources of resistance, the actual available or effective pressure of steam upon the piston is at the rate of 7 lbs. per square inch of piston surface. The total nominal effective action of the piston in pounds will therefore be found by multiplying the number of square inches in the area of the piston by 7.

93. In the following tables, obtained from the government authorities, will be found a complete statement of the strength of her Majesty's steam navy up to the 1st of April, 1856.

By Table I. it appears that the number of line-of-battle ships fitted and fitting with the screw-propeller was then 43, carrying a total number of 3797 guns, and propelled by engines of the collective power of 22950 horses. This is at the average rate of 88⅓ guns, and 533 horses per vessel; the proportion of guns to horses being about 6 horses per gun.

By Table II. it appears that the number of frigates and mortar-ships was 24, carrying collectively 889 guns, and propelled by engines of 10560 horse-power, being at the average rate of 37 guns, and 440 horses per vessel; the proportion of horses to guns being about 12 horses per gun.

By Table III. it appears that there were 90 war steamers fitted with paddle-wheels, carrying the total number of 500 guns, and propelled by engines having the collective power of 24640 horses, being at the average rate of 5½ guns, and 274 horses per vessel; the proportion of horse-power to guns being about 50 horses per gun.

By Table IV. it appears that there were 76 smaller vessels fitted with screw-propellers, consisting of corvettes, sloops, and despatch boats, carrying in all 761 guns, and propelled by engines of the collective power of 16202 horses, being at the average rate of 10 guns and 213 horses per vessel; the proportion of horse-power to guns being therefore about 21 horses per gun.

In Table V. is given the number and power of the troop and store-ships, water-tanks, &c.; in Table VI. a statement of the

steam-propelled gun-boats; and in Table VII. a general summary of the entire steam navy.

In Table VIII. is given a statement of the commercial steam navy in March 1853.

TABLE I.

Line-of-Battle Ships fitted and fitting with the Screw-Propeller in Her Majesty's Navy.

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Agamemnon	91	600		Brought forward	1253	7500		Brought forward	2475	14700
2	Ajax	60	450	16	Exmouth	90	400	30	Orion	91	600
3	Algiers	90	450	17	Gibraltar	100	800	31	Pembroke	60	200
4	Blenheim	60	450	18	Hannibal	90	450	32	Princess Royal	91	400
5	Brunswick	80	400	19	Hastings	60	200	33	Renown	90	800
6	Cæsar	91	400	20	Hawke	60	200	34	Revenge	90	800
7	Centurion	80	400	21	Hero	90	600	35	Royal Albert	121	500
8	Colossus	80	400	22	Hogue	60	450	36	Royal George	102	400
9	Conqueror	100	800	23	Howe	120	1000	37	Royal Sovereign	120	1000
10	Cornwallis	60	200	24	Irresistible	80	400	38	Russell	60	200
11	Cressy	80	400	25	James Watt	91	600	39	St. Jean d'Acre	101	600
12	Donegal	100	800	26	Majestic	80	400	40	Sanspareil	70	350
13	D. of Wellington	131	700	27	Marlborough	130	800	41	Victor Emanuel	90	600
14	Edgar	90	600	28	Mars	80	400	42	Victoria	120	1000
15	Edinburgh	60	450	29	Nile	91	500	43	Windsor Castle	116	800
		1253	7500			2475	14700		Total	3797	22950

TABLE II.

Frigates and Mortar-ships fitted and fitting with the Screw-Propeller in Her Majesty's Navy.

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Amphion	34	300		Bt. forward	355	4140		Bt. forward	621	7350
2	Ariadne	30	350	10	Doris	32	800	18	Liffey	50	600
3	Arrogant	46	360	11	Emerald	50	600	19	San Fiorenzo	50	600
4	Aurora	50	400	12	Eurotas	12	200	20	Sea-horse	12	200
5	Bacchante	50	600	13	Euryalus	51	400	21	Shannon	51	600
6	Chesapeake	50	400	14	Forte	50	400	22	Termagant	24	310
7	Curaçoa	30	350	15	Forth	12	200	23	Topaz	50	600
8	Dauntless	33	580	16	Horatio	8	250	24	Tribune	31	300
9	Diadem	32	800	17	Impérieuse	51	360		Total	889	10560
		355	4140			621	7350				

TABLE III.—*A List of War Steamers in Her Majesty's Service fitted with Paddle-wheels.*

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Alecto	5	200		Bt. forward	112	7560		Bt. forward	283	15869
2	Albany	4	100	32	Furious	16	400	62	Penelope	16	650
3	Ardent	5	200	33	Fury	..	515	63	Porcupine	3	132
4	Antelope	3	260	34	Geyser	6	280	64	Prometheus	5	200
5	Argus	6	300	35	Gorgon	6	320	65	Rhadamanthus	4	220
6	Asp	..	50	36	Gladiator	6	430	66	Redpole	1	160
7	Avon	3	160	37	Harpy	1	200	67	Retribution	28	400
8	Bann	..	80	38	Hecate	6	240	68	Rosamond	6	280
9	Banshee	2	350	39	Hecla	6	240	69	Sampson	6	467
10	Barracouta	6	300	40	Hermes	6	220	70	Salamander	6	220
11	Basilisk	6	400	41	Hydra	6	220	71	Scourge	6	420
12	Black Eagle	..	260	42	Inflexible	6	378	72	Shearwater	8	160
13	Blood Hound	3	150	43	Jackal	4	150	73	Sidon	22	560
14	Brune	..	80	44	Kite	3	170	74	Spiteful	6	280
15	Bull Dog	6	500	45	Leopard	18	560	75	Spitfire	5	140
16	Buzzard	6	300	46	Lightning	3	100	76	Sphinx	6	500
17	Caradoc	2	350	47	Lizard	1	150	77	Stromboli	6	280
18	Centaur	6	540	48	Locust	3	100	78	Styx	6	280
19	Columbia	6	100	49	Lucifer	2	180	79	Tartarus	4	136
20	Comet	..	80	50	Magicienne	16	400	80	Terrible	21	800
21	Cuckoo	3	100	51	Medea	6	350	81	Trident	6	350
22	Cyclops	6	320	52	Medina	4	312	82	Triton	3	260
23	Dasher	2	100	53	Medusa	4	312	83	Valorous	16	400
24	Dee	4	200	54	Merlin	6	312	84	Vesuvius	6	280
25	Devastation	6	400	55	Oberon	3	260	85	Virago	6	300
26	Dragon	6	560	56	Odin	16	560	86	Vulture	6	470
27	Dover	..	90	57	Osborne	2	430	87	Weser	6	160
28	Driver	6	280	58	Otter	3	120	88	Widgeon	..	90
29	Firefly	4	220	59	Pigmy	3	100	89	Wildfire	..	76
30	Firebrand	6	410	60	Polyphemus	5	200	90	Zephyr	3	100
31	Fire Queen	..	120	61	Pluto	4	100				
		112	7560			283	15869		Total	500	24640

TABLE IV.—*Corvettes, Sloops, and Despatch Gun-vessels fitted and fitting with the Screw-Propeller in Her Majesty's Service.*

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Alacrity		200		Bt. forward	305	5700		Bt. forward	541	1090
2	Alert	16	100	27	Flying Fish	6	350	52	Plumper	9	600
3	Ariel	9	60	28	Fox Hound	4	200	53	Pylades	20	350
4	Archer	14	202	29	Harrier	17	100	54	Rattler	11	200
5	Arrow	4	160	30	Hesperus	..	120	55	Recruit	6	160
6	Assurance	4	200	31	Highflyers	21	250	56	Renard	4	200
7	Beagle	4	160	32	Hornet	17	100	57	Rifleman	8	100
8	Brisk	14	250	33	Icarus	..	..	58	Ringdove	4	200
9	Cadmus	20	400	34	Intrepid	6	350	59	Roebuck	6	350
10	Cameleon	16	100	35	Lapwing	4	200	60	Reward	4	200
11	Challenger	20	400	36	Lynx	4	160	61	Satellite	20	400
12	Charybdis	20	400	37	Lyra	8	60	62	Scout	20	400
13	Clio	20	400	38	Malacca	17	200	63	Scylla	20	400
14	Conflict	8	400	39	Minx	3	10	64	Sharpshooter	8	202
15	Coquette	4	200	40	Miranda	14	250	65	Snake	4	160
16	Cordelia	8	60	41	Mohawk	4	200	66	Sparrowhawk	4	200
17	Cormorant	4	200	42	Mutine	16	100	67	Surprise	4	200
18	Cossack	20	250	43	Myrmidon	3	150	68	Swallow	9	60
19	Cruiser	17	60	44	Niger	14	400	69	Tartar	20	250
20	Curlew	9	60	45	Nimrod	6	350	70	Teazer	3	40
21	Desperate	8	400	46	Osprey	4	200	71	Victor	6	350
22	Encounter	14	360	47	Pearl	20	400	72	Vigilant	4	200
23	Esk	21	250	48	Pelican	16	100	73	Viper	4	160
24	Etna	14	200	49	Pelorus	20	400	74	Wanderer	4	200
25	Falcon	17	100	50	Phœnix	6	200	75	Wasp	14	100
26	Fawn	..	128	51	Pioneer	6	350	76	Wrangler	4	160
		305	5700			541	10900		Total	761	16202

TABLE V.—*Trooper, Store-ships, Water-tanks, Flour-mills, Yachts, and Floating-factories.*

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Abundance . .	..	100		Bt. forward .		1856		Bt. forward .	11	4076
2	Assistance . .	..	400	18	Hearty . .	..	100	34	Prospero . .	..	144
3	Advice . .	..	100	19	Helen Faucit .	..	..	35	Resistance . .	10	400
4	Adder . .	..	100	20	Himalaya . .	..	700	36	Resolute . .	..	400
5	African . . .	..	90	21	Humber . .	..	30	37	Simoom . .	8	350
6	Bruiser . .	..	100	22	Industry . .	2	80	38	Sprightly . .	..	100
7	Buffalo . .	..	60	23	Malta . .	..	50	39	Supply . .	2	80
8	Bustler . .	..	100	24	Megæra . .	6	350	40	Sulina . .	..	120
9	Chasseur . .	..	100	25	Monkey . .	..	130	41	Sultana . .	..	..
10	Confiance .	..	100	26	Moslem . .	..	120	42	Thais . .	..	80
11	Coromandel .	..	..	27	Myrtle . .	..	50	43	Torch . . .	..	150
12	Crescent . .	..	50	28	Nimble . .	..	..	44	Transit . .	..	500
13	Danube . .	..	..	29	Pera . . .	..	30	45	Urgent . .	..	450
14	Echo . .	..	140	30	Perseverance .	2	360	46	Vulcan . .	6	350
15	Elfin . . .	..	140	31	Pike . . .	..	50	47	Wye . . .	..	100
16	Fearless . .	..	76	32	Pigeon . . .	..	50				
17	Fox . . .	..	200	33	Princess Alice .	1	120		Total . .	37	7300
			1856			11	4076				

TABLE VI.

Statement of the Total Number and Power of Steam Gun-boats in the Royal Navy on the 1st *April,* 1856.

No.	Guns.	Horse Power.	Total Guns.	Total Horse Power.
122	4	60	488	7320
13	4	40	52	520
20	2	20	40	400
155	10	120	580	8240

TABLE VII.

Statement of the Number and Power of Steam Vessels of all classes in the Royal Navy on the 1st *April,* 1856.

	No.	Guns.	Horse Power.
Line-of-Battle Ships .	43	3797	22950
Frigates & Mortar-ships.	24	889	10560
Paddle-wheel Vessels .	90	500	24640
Corvettes, Sloops, &c. .	76	761	16202
Troop-ships . . .	47	37	7300
Gun-boats	155	580	8240
	435	6564	89892

TABLE VIII.—*Showing the number of vessels (wood and iron) belonging to the Mail Contract Steam Packet Companies in March,* 1853; *also their Tonnage and Horse Power, from Parliamentary return ordered to be printed* 29*th June,* 1853.

To what Company belonging.	Number of Vessels.			Tonnage.			Horse Power.		
	Wood.	Iron.	Total.	Wood.	Iron.	Total.	Wood.	Iron.	Total.
Peninsula and Oriental	11	22	33	11800	26449	38249	4086	7481	11567
Royal West India . .	19	1	20	32612	2700	35312	8750	800	9550
British and N. American	8	1	9	14991	2500	17491	5690	1000	6690
Pacific	..	8	8	..	6688	6688	..	2298	2298
General Screw Steam Shipping . .	..	8	8	..	13496	13496	..	2250	2250
Australian	..	5	5	..	8600	8600	..	1800	1800
South Western . .	..	4	4	..	1612	1612	..	677	677
African	..	4	4	..	3920	3920	..	530	530
Total . . .	38	53		59403	65965		18526	16836	
	Grand total		91	Grand total		125368	Grand total		35362

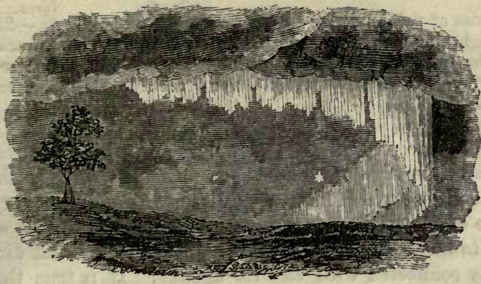


Fig. 4.

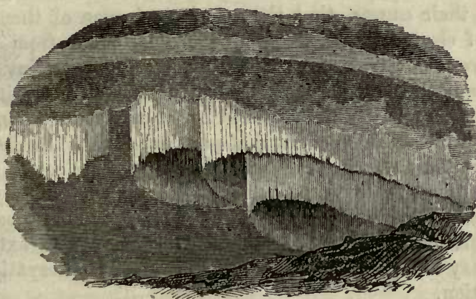


Fig. 5.

THUNDER AND LIGHTNING, AND THE AURORA BOREALIS.

1. Atmospheric Electricity.—2. The air generally charged with positive electricity.—3. Subject to variations and exceptions.—4. Diurnal variations of electrical intensity. Observations of Quetelet. — 5. Irregular and local variations and exceptions. — 6. Variations dependent on the season and weather.—7. Methods of observing atmospheric electricity.—8. Methods of ascertaining the electrical condition of the higher strata.—9. Remarkable experiments of Romas, 1757.—10. Electrical charge of clouds varies.—11. Thunder and lightning.—12. Form and extent of the flash of lightning.—13. Cause of the rolling of thunder.—14. Affected by the zigzag form of lightning.—15. Affected by the varying distance of different parts of the flash.—16. Affected by echo and by interference.—17. Inductive action of clouds on the earth.—18. Formation of Fulgurites explained. —19. Accidents of the surface which attract lightning.—20. Lightning follows conductors by preference—its effects on buildings.—21. Con-

ductors or paratonnerres for the protection of buildings.—22. Effects of lightning on bodies which it strikes.—23. The Aurora Borealis — the phenomena unexplained. — 24. General character of the meteor.—25. Description of auroras seen in the polar regions by M. Lottin.

1. There is no part of physical science in which the researches of modern investigators have been attended with such signal success, as those which have been directed to the discovery of the influence of electricity upon the atmosphere. Indeed it would be difficult to name any atmospheric change, which is not directly or indirectly connected with electric agency. It is true that these atmospheric phenomena, fugitive and transitory as most of them are, have not been in all cases traced with clearness and certainty to their causes, that the relation of some of them to the agency of electricity is rendered probable, more from general appearances than by distinct and satisfactory demonstration, and that some of them, which are evidently of electric origin, have, nevertheless, remained unexplained by, or not reduced to, any of the known laws which govern that physical agent. Still there is much that falls under the general principles of electric science, and those phenomena which remain with or without any satisfactory explanation require to be stated, that those who pursue this part of physical science, with a view to extend its limits, may be guided to proper subjects of observation and investigation.

How important the topics embraced under the general head of atmospheric electricity are, will be understood when it is stated, that upon the electric condition of the atmosphere, and the changes incidental to it, depend not only the stupendous phenomena of thunder-storms, but also the whole of that beautiful and interesting class of phenomena comprised under the general name of Aurora Borealis.

2. The terrestrial globe which we inhabit is invested with an ocean of air, the depth of which is about the 200th part of its diameter. It may, therefore, be conceived by imagining a coating of air, the tenth of an inch thick, investing a twenty-inch globe. This aerial ocean, relatively shallow as it is, at the bottom of which the tribes of organised nature have their dwelling, is, nevertheless, the theatre of stupendous electrical phenomena.

It may be stated as a general fact, that the atmosphere which thus covers the globe is charged with positive electricity, which, acting by induction on the superficial stratum of the globe on which it rests, decomposes the natural electricity, attracting the negative fluid to the surface and repelling the positive fluid to

the inferior strata. The globe and its atmosphere may therefore be not inaptly compared to a Leyden phial, the outer coating of which being placed in connection with the prime conductor of a machine, is charged with positive electricity, and the inner coating being in connection with the ground, is charged by induction with negative electricity. The outer coating represents the atmosphere, and the inner the superficial stratum of the globe.

3. This normal state of the general atmospheric ocean is subject to variations and exceptions, variations of intensity and exceptions in quality or name. The variations are periodical and accidental. The exceptions local, patches of the general atmosphere in which clouds float being occasionally charged with negative electricity.

4. The intensity of the electricity with which the atmosphere is charged, varies, in the course of twenty-four hours, alternately increasing and decreasing. M. Quetelet found that the first maximum was manifested about 8 A.M., and the second about 9 P.M. The minimum in the day was at 3 P.M. He found also that the mean intensity was greatest in January and least in June.

5. Such are the normal changes which the electrical condition of the air undergoes when the atmosphere is clear and unclouded. When, however, the firmament is covered with clouds, the electricity is subject during the day to frequent and irregular changes not only in intensity but in name; the electricity being often negative, owing to the presence of clouds over the place of observation, charged, some with positive, and some with negative electricity.

6. The intensity of the electricity of the air is also affected by the season of the year, and by the prevalent character and direction of the winds; it varies also with the elevation of the strata, being in general greater in the higher than in the lower regions of the atmosphere. The intensity is generally greater in winter, and especially in frosty weather, than in summer, and when the air is calm than when winds prevail.

Atmospheric deposits, such as rain, hail, snow, &c., are sometimes positive and sometimes negative, varying with the direction of the wind. North winds give positive, and south winds negative deposits.

7. The electricity of the atmosphere is observed by erecting in it, to any desired elevation, pointed metallic conductors, from the lower extremities of which wires are carried to electroscopes of various forms, according to the intensity of the electricity to be observed. So immediate is the increase of electrical tension in rising through the strata of the air, that a gold leaf electroscope,

properly adapted to the purpose, and reduced to its natural state when placed horizontally on the ground, will show a sensible divergence when raised to the level of the eyes.

8. To ascertain the electrical condition of strata too elevated to be reached by a fixed conductor, the extremity of a flexible wire, to which a metallic point is attached, is connected with a heavy ball, which is projected into the air by a gun or pistol, or to an arrow projected by a bow. The projectile, when it attains the limit of its flight, detaches the wire from the electroscope, which then indicates the electrical state of the air at the highest point attained by the projectile.

9. The vast quantities of electricity with which the clouds are sometimes charged, were rendered manifest in a striking manner by the well-known experiments made by means of kites by Romas in 1757. The kite, carrying a metallic point, was elevated to the strata in which the electric cloud floated. A wire was connected with the cord, and carried from the pointed conductor borne by the kite to a part of the cord at some distance from the lower extremity, where it was turned aside and brought into connection with an electroscope, or other experimental means of testing the quantity and quality of the electricity with which it was charged. Romas drew from the extremity of this conducting wire not only strong electric sparks, but blades of fire nine or ten feet in length, and an inch in thickness, the discharge of which was attended with a report as loud as that of a pistol. In less time than an hour, not less than thirty flashes of this magnitude and intensity were often drawn from the conductor, besides many of six or seven feet and of less length.

10. It has been shown by means of kites thus applied, that the clouds are charged some with positive and some with negative electricity, while some are observed to be in their natural state. These circumstances serve to explain some phenomena observed in the motions of the clouds which are manifested in stormy weather. Clouds which are similarly electrified repel, and those which are oppositely electrified attract each other. Hence arise motions among such clouds of the most opposite and complicated kind. While they are thus reciprocally attracted and repelled in virtue of the electricity with which they are charged, they are also transported in various directions by the currents which prevail in the atmospheric strata in which they float, these currents often having themselves different directions.

11. Such appearances are the sure prognostics of a thunderstorm. Clouds charged with contrary electricities affect each other by induction, and mutually attract, whether they float in the same stratum or in strata at different elevations. When they

come within *striking distance*, the contrary fluids rush to each other, and an electrical discharge takes place.

The clouds, however, unlike the metallic coatings of the jar, are very imperfect conductors, and consequently, when discharged at one part of their vast extent, they preserve elsewhere their electricity in its original intensity. Thus, the first discharge, instead of establishing equilibrium, rather disturbs it, for the part of the cloud which is still charged is alone attracted by the part of the other cloud in which the fluid has not yet been neutralised. Hence arise various and complicated motions and variations of form of the clouds, and a succession of discharges between the same clouds must take place before the electrical equilibrium is established. This is necessarily attended by a corresponding succession of flashes of lightning and claps of thunder.

12. The form of the flash in the case of lightning, like that of the spark taken from an electrified conductor, is zigzag. The doublings or acute angles formed at the successive points when the flash changes its direction vary in number and proximity. The cause of this zigzag course, whether of the electric spark or of lightning, has not been explained in any clear or satisfactory manner.

The length of the flashes of lightning also varies; in some cases they have been ascertained to extend to from two-and-a-half to three miles. It is probable, if not certain, that the line of light exhibited by flashes of forked lightning are not in reality one continued line simultaneously luminous, but that on the contrary the light is developed successively as the electricity proceeds in its course, the appearance of a continuous line of light being an optical effect, analogous to the continuous line of light exhibited when a lighted stick is moved rapidly in a circle, the same explanation being applicable to the case of lightning.

13. As the sound of thunder is produced by the passage of the electric fluid through the air which it suddenly compresses, it is evolved progressively along the entire space along which the lightning moves. But since sound moves only at the rate of 1100 feet per second, while the transmission of light is so rapid that in this case it may be considered as practically instantaneous, the sound will not reach the ear for an interval greater or less after the perception of the light, just as the flash of a gun is seen before the report is heard.

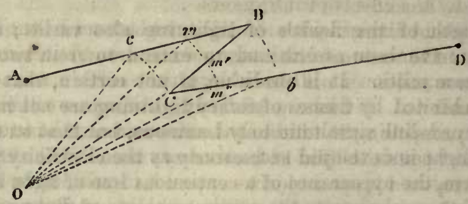
By noting the interval, therefore, which elapses between the perception of the flash and that of the sound, the distance of the point where the discharge takes place can be computed approximately, by allowing 1100 feet for every second in the interval.

But since a separate sound is produced at every point through which the flash passes, and as these points are at distances from the observer which vary according to the position, length, direction, and form of the flash, it will follow necessarily that the sounds produced by the same flash, though practically simultaneous, because of the great velocity with which the electricity moves, arrive at the ear in comparatively slow succession.

The varying loudness of the successive sounds heard in the rolling of thunder, proceeds in part from the same causes as the varying intensity of the light of the flash. But it may, perhaps, be more satisfactorily explained by the combination of the successive discharges of the same cloud, rapidly succeeding each other, and combining their effects with those arising from the varying distances of different parts of the same flash.

14. It appears to us that the varying intensity of the rolling of thunder may also be very clearly and satisfactorily explained by the zigzag form of the flash, combined with the effect of the varying distance; and it seems extraordinary that an explanation so obvious has not been suggested. Let A, B, C, D (fig. 1), be a

Fig. 1.



part of a zigzag flash seen by an observer at O. Taking O as a centre, suppose arcs C c and B b of circles to be drawn, with O C and O B as radii. It is clear that the points C and c, and B and b, being respectively equally distant from the observer, the sounds produced there will be heard simultaneously, and, supposing them equal, will produce the perception of a sound twice as loud as either heard alone would do. All the points on the zigzag c B C b are so placed that three of them are equi-distant from O. Thus, if with O as centre, and O m as radius, a circular arc be described, it will intersect the path of the lightning at three points m, m', and m'', and these three points being, therefore, at the same distance from O, the sounds produced at them will reach the observer at the same moment, and if they be equally intense will produce on the ear the same effect as a single sound three times as loud. The same will be true for all the points of the zigzag between c and b. Thus, in this case,

supposing the intensity of the lightning to be uniform from A to D, there will be three degrees of loudness in the sound produced, the least between A and *c* and between *b* and D, the greatest between *c* and *b* along the zigzag, and the intermediate at the points C *c* and B *b*.

It is evident, that from the infinite variety of form and position with relation to the observer, of which the course of the lightning is susceptible, the variations of intensity of the rolling of thunder which may be explained in this way have no limit.

15. Since the loudness of a sound diminishes as the square of the distance of the observer is increased, it is clear that this affords another means of explaining the varying loudness of the rolling of thunder.

16. As the rolling of thunder is much more varied and of longer continuance in mountainous regions than in open plain countries, it is no doubt also affected by reverberation from every surface capable of reflecting sound, which it encounters. A part therefore of the rolling must be in such cases the effect of echo.

It has been also conjectured that the acoustic effects are modified by the effects of interference.

17. A cloud charged with electricity, whatever be the quality of the fluid or the state of the atmosphere around it, exercises by induction an action on all bodies upon the earth's surface immediately under it. It has a tendency to decompose their natural electricity, repelling the fluid of the same name, and attracting to the highest points the fluid of a contrary name. The effects thus actually produced upon objects exposed to such induction, will depend on the intensity and quality of the electricity with which the cloud is charged, its distance, the conductibility of the materials of which the bodies affected consist, their magnitude, position, and, above all, their form.

Water being a much better conductor than earth in any state of aggregation, thunder clouds act with great energy on the sea, lakes, and other large collections of water. The flash has a tendency to pass between the cloud and the water, just as the spark passes between the conductor of an electric machine and the hand presented to it.

18. This explains the fact that lightning sometimes penetrates strata of the solid ground, under which subterranean reservoirs of water are found. The water of such reservoirs is affected by the inductive action of an electrified cloud, and in its turn reacts upon the cloud, as one coating of a Leyden jar reacts upon the other. When this mutual action is sufficiently strong to overcome the resistance of the subjacent atmosphere, and the strata of

soil under which the subterranean reservoir lies, a discharge takes place, and the lightning penetrates the strata, fusing the materials of which it is composed, and leaving a tubular hole with a hard vitrified coating.

Tubes thus formed have been called *fulgurites*, or *thunder tubes*.

19. The well known properties of points, edges, and other projecting parts of conductors, will render easily intelligible the influence of mountains, peaked hills, projecting rocks, trees, lofty edifices, and other objects, natural and artificial, which project upwards from the general surface of the ground. Lightning never strikes the bottom of deep and close valleys. In Switzerland, on the slopes of the Alps and Pyrenees, and in other mountainous countries, multitudes of cultivated valleys are found, the inhabitants of which know by secular tradition that they have nothing to fear from thunder-storms. If, however, the width of the valleys were so great as twenty or thirty times their depth, clouds would occasionally descend upon them in masses sufficiently considerable, and lightning would strike.

Solitary hills, or elevated buildings rising in the centre of an extensive plain, are peculiarly exposed to lightning, since there are no other projecting objects near them to divert its course.

Trees, especially if they stand singly apart from others, are likely to be struck. Being from their nature more or less impregnated with sap, which is a conductor of electricity, they attract the fluid, and are struck.

The effects of such objects are, however, sometimes modified by the agency of unseen causes below the surface. The condition of the soil, subsoil, and even the inferior strata, the depth of the roots and their dimensions, also exercise considerable influence on the phenomena, so that in the places where there is the greatest apparent safety there is often the greatest danger. It is, nevertheless, a good general maxim not to take a position in a thunder-storm either under a tree or close to an elevated building, but to keep as much as possible in the open plain.

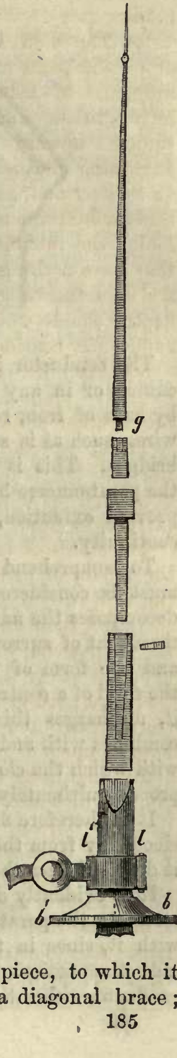
20. Lightning falling upon buildings chooses by preference the points which are the best conductors. It sometimes strikes and destroys objects which are non-conductors, but this happens generally when such bodies lie in its direct course towards conductors. Thus lightning has been found to penetrate a wall attracted by a mass of metal placed within it.

Metallic roofs, beams, braces, and other parts in buildings, are liable thus to attract lightning. The heated and rarefied air in chimneys acquires conductibility. Hence it happens often that lightning descends chimneys, and thus passes into rooms. It

follows bell-wires, metallic mouldings of walls and furniture, and fuses gilding.

21. The purpose of paratonnerres or conductors, erected for the protection of buildings, is not to repel, but rather to attract lightning, and divert it into a course in which it will be innoxious.

Fig. 2.



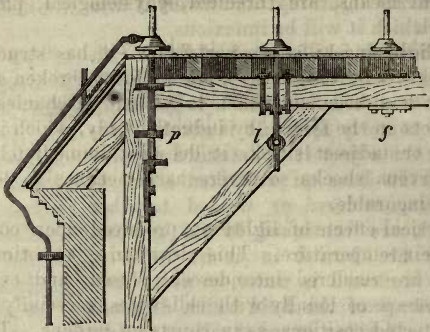
A paratonnerre is a pointed metallic rod, the length of which varies with the building on which it is placed, but which is generally from thirty to forty feet. It is erected vertically over the object it is intended to protect. From its base an unbroken series of metallic bars, soldered or welded together end to end, are continued to the ground, where they are buried in moist soil, or, better still, immersed in water, so as to facilitate the escape of the fluid which descends upon them. If water, or moist soil, cannot be conveniently found, it should be connected with a sheet of metal of considerable superficial magnitude, buried in a pit filled with pounded charcoal, or, better still, with *braise*.

The parts of a well-constructed paratonnerre are represented in fig. 2. The rod, which is of iron, is round at its base, then square, and decreases gradually in thickness to the summit. It is composed commonly of three pieces closely jointed together, and secured by pins passed transversely through them. In the figure are represented only the two extremities of the lowest, and those of the intermediate piece, to avoid giving inconvenient magnitude to the diagram. The superior piece, *g*, is represented complete. It is a rod of brass or copper, about two feet in length, terminating in a platinum point about three inches long, attached to the rod by silver solder, which is further secured by a brass ferule, which gives the projecting appearance in the diagram below the point.

Three of the methods, reputed the most efficient for attaching the paratonnerre to the roof, are represented in fig. 3, at *p*, *l*, and *f*. At *p* the rod is supported against a vertical piece, to which it is attached by stirrups; at *l* it is bolted upon a diagonal brace;

and at *f* it is simply secured by bolts to a horizontal beam through which it passes. The last is evidently the least solid method of fixing it.

Fig. 3.



The conductor is continued downwards along the wall of the edifice, or in any other convenient course, to the ground, either by bars of iron, round or square, or by a cable of iron or copper wires, such as is sometimes used for the lighter sort of suspension bridges. This is attached, at its upper extremity, to the base of the paratonnerre by a joint, which is hermetically closed, so as to prevent oxidation, which would produce a dangerous solution of continuity.

To comprehend the protective influence of this apparatus, it must be considered that the inductive action of a thunder-cloud decomposes the natural electricity of the rod, more energetically than that of surrounding objects, both on account of the material and the form of the rod. The point becoming surcharged with the fluid of a contrary name from that of the cloud suspended over it, discharges this fluid in a jet towards the cloud, where it combines with and neutralises an equal quantity of the electricity with which the cloud is charged, and, by the continuance of this process, ultimately reduces the cloud to its natural state.

It is therefore more correct to say that the paratonnerre draws electricity from the ground and projects it to the cloud, than that it draws it from the cloud and transmits it to the earth.

It is evidently desirable that all conducting bodies to be protected by the paratonnerre, should be placed in metallic connection with it, since in that case their electricity, decomposed by the inductive action of the clouds, will necessarily escape by the conductor either to the earth or to the cloud by the point.

It is considered generally that the range of protection of a paratonnerre is a circle round its base, whose radius is two or three times its length.

22. The effects of lightning, like those of electricity evolved by artificial means, are threefold, physiological, physical, and mechanical.

When lightning kills, the parts where it has struck bear the marks of severe burning; the bones are often broken and crushed as if they had been subjected to violent mechanical pressure. When it acts on the system by induction only, which is called the secondary or indirect shock, it does not immediately kill, but inflicts nervous shocks so severe as sometimes to leave effects which are incurable.

The physical effects of lightning produced upon conductors is to raise their temperature. This elevation is sometimes so great that they are rendered incandescent, fused, and even burned. This happens occasionally with bell-wires, especially in exposed and unprotected positions, as in courts or gardens. The drops of molten metal produced in such cases set fire to any combustible matter on which they may chance to fall. Wood, straw, and such non-conducting bodies are ignited generally by the lightning drawn through them, by the attraction of other bodies near them which are good conductors.

The mechanical effects of lightning, the physical cause of which has not been satisfactorily explained, are very extraordinary. Enormous masses of metal are torn from their supports, vast blocks of stone are broken, and massive buildings are razed to the ground.

23. No theory or hypothesis which has commanded general acceptation, has yet been suggested for the explanation of the Aurora Borealis. All the appearances which attend the phenomenon are, however, electrical; and its forms, directions, and positions, though ever varying, always bear a remarkable relation to the magnetic meridians and poles. Whatever, therefore, be its physical cause, it is evident that the theatre of its action is the atmosphere; and that the agent to which the development is due, is electricity, influenced in some unascertained manner by terrestrial magnetism. In the absence of any satisfactory theory for the explanation of the phenomenon, we shall confine ourselves here to a short description of it, derived from the most extensive and exact series of observations which have been made in those regions, where the meteor has been seen with the most marked characters and in the greatest splendour.

24. The Aurora Borealis is a luminous phenomenon which appears in the heavens, and is seen in high latitudes in both

hemispheres. The term Aurora Borealis, or Northern Lights, has been applied to it, because the opportunities of witnessing it are, from the geographical character of the globe, much more frequent in the northern than in the southern hemisphere. The term *aurora polaris* would be a more proper designation.

This phenomenon consists of luminous rays of various colours, issuing from every direction, but converging to the same point, which appear after sunset generally toward the north, occasionally toward the west, and sometimes, but rarely, toward the south. It frequently appears near the horizon, as a vague and diffused light, something like the faint streaks which harbinger the rising sun and form the dawn. Hence the phenomenon has derived its name, which signifies *northern morning.* Sometimes, however, it is presented under the form of a sombre cloud, from which luminous jets issue, which are often variously coloured, and illuminate the entire atmosphere.

The more conspicuous auroras commence to be formed soon after the close of twilight. At first a dark mist or foggy cloud is perceived in the north, and a little more brightness towards the west than in the other parts of the heavens. The mist gradually takes the form of a circular segment, resting at each corner on the horizon. The visible part of the arc soon becomes surrounded with a pale light, which is followed by the formation of one or several luminous arcs. Then come jets and rays of light variously coloured, which issue from the dark part of the segment, the continuity of which is broken by bright emanations, indicating a movement of the mass, which seems agitated by internal shocks, during the formation of these luminous radiations, that issue from it as flames do from a conflagration. When this species of fire has ceased, and the aurora has become extended, a crown is formed at the zenith, to which these rays converge. From this time the phenomenon diminishes in its intensity, exhibiting, nevertheless, from time to time, sometimes on one side of the heavens and sometimes on another, jets of light, a crown, and colours more or less vivid. Finally the motion ceases, the light approaches gradually to the horizon ; and the cloud, quitting the other parts of the firmament, settles in the north. The dark part of the segment becomes luminous, its brightness being greatest near the horizon, and becoming more feeble as the altitude augments, until it loses its light altogether.

The aurora is sometimes composed of two luminous segments, which are concentric, and separated from each other by one dark space, and from the earth by another. Sometimes, though rarely, there is only one dark segment, which is symmetrically pierced round its border by openings, through which light or fire is seen.

25. One of the most recent and exact descriptions of this meteor is the following, supplied by M. Lottin, an officer of the French navy, and a member of the Scientific Commission sent some years ago to the North Seas. Between September, 1838, and April, 1839, this savant observed nearly 150 meteors of this class. They were most frequent from the 17th November to the 25th January, being the interval during which the sun remained constantly below the horizon. During this period there were sixty-four auroras visible, besides many which a clouded sky concealed from the eye, but the presence of which was indicated by the disturbances they produced upon the magnetic needle.

The succession of appearances and changes presented by these meteors are thus described by M. Lottin:—

Between four and eight o'clock, P.M., a light fog, rising to the altitude of six degrees, became coloured on its upper edge, being fringed with the light of the meteor rising behind it. This border becoming gradually more regular, took the form of an arc, of a pale yellow colour, the edges of which were diffuse, the extremities resting on the horizon. This bow swelled slowly upwards, its vertex being constantly on the magnetic meridian. Blackish streaks divided regularly the luminous arc, and resolved it into a system of rays; these rays were alternately extended and contracted; sometimes slowly, sometimes instantaneously; sometimes they would dart out, increasing and diminishing suddenly in splendour. The inferior parts, or the feet of the rays, presented always the most vivid light, and formed an arc more or less regular. The length of these rays was very various, but they all converged to that point of the heavens, indicated by the direction of the southern pole of the dipping needle. Sometimes they were prolonged to the point where their directions intersected, and formed the summit of an enormous dome of light.

The bow then would continue to ascend toward the zenith: it would suffer an undulatory motion in its light—that is to say, that from one extremity to the other the brightness of the rays would increase successively in intensity. This luminous current would appear several times in quick succession, and it would pass much more frequently from west to east than in the opposite direction. Sometimes, but rarely, a retrograde motion would take place immediately afterward; and as soon as this wave of light had run successively over all the rays of the aurora from west to east, it would return, in the contrary direction, to the point of its departure, producing such an effect that it was impossible to say whether the rays themselves were actually affected by a motion of translation in a direction nearly horizontal, or if this more vivid light was transferred from ray to ray,

the system of rays themselves suffering no change of position. The bow, thus presenting the appearance of an alternate motion in a direction nearly horizontal, had usually the appearance of the undulations or folds of a ribbon or flag agitated by the wind. Sometimes one, and sometimes both of its extremities would desert the horizon, and then its folds would become more numerous and marked, the bow would change its character, and assume the form of a long sheet of rays returning into itself, and consisting of several parts forming graceful curves. The brightness of the rays would vary suddenly, sometimes surpassing in splendour stars of the first magnitude; these rays would rapidly dart out, and curves would be formed and developed like the folds of a serpent; then the rays would affect various colours, the base would be red, the middle green, and the remainder would preserve its clear yellow hue. Such was the arrangement which the colours always preserved; they were of admirable transparency, the base exhibiting blood-red, and the green of the middle being that of the pale emerald; the brightness would diminish, the colours disappear, and all be extinguished, sometimes suddenly, and sometimes by slow degrees. After this disappearance, fragments of the bow would be reproduced, would continue their upward movement, and approach the zenith; the rays, by the effect of perspective, would be gradually shortened; the thickness of the arc, which presented then the appearance of a large zone of parallel rays, would be estimated; then the vertex of the bow would reach the magnetic zenith, or the point to which the south pole of the dipping needle is directed. At that moment the rays would be seen in the direction of their feet. If they were coloured, they would appear as a large red band, through which the green tints of their superior parts could be distinguished; and if the wave of light above mentioned passed along them, their feet would form a a long sinuous undulating zone; while, throughout all these changes, the rays would never suffer any oscillation in the direction of their axis, and would constantly preserve their mutual parallelisms.

While these appearances are manifested, new bows are formed, either commencing in the same diffuse manner, or with vivid and ready-formed rays: they succeed each other, passing through nearly the same phases, and arrange themselves at certain distances from each other. As many as nine have been counted, having their ends supported on the earth, and, in their arrangement, resembling the short curtains suspended one behind the other over the scene of a theatre, and intended to represent the sky. Sometimes the intervals between these bows diminish, and two or more of them close upon each other, forming one large zone,

traversing the heavens, and disappearing towards the south, becoming rapidly feeble after passing the zenith. But sometimes, also, when this zone extends over the summit of the firmament from east to west, the mass of rays appears suddenly to come from the south, and to form with those from the north the real boreal corona, all the rays of which converge to the zenith. This appearance of a crown, therefore, is doubtless the mere effect of perspective; and an observer, placed at the same instant at a certain distance to the north or to the south, would perceive only an arc.

The total zone, measuring less in the direction north and south than in the direction east and west, since it often leans upon the earth, the corona would be expected to have an elliptical form; but that does not always happen: it has been seen circular, the unequal rays not extending to a greater distance than from eight to twelve degrees from the zenith, while at other times they reach the horizon.

Let it, then, be imagined, that all these vivid rays of light issue forth with splendour, subject to continual and sudden variations in their length and brightness; that these beautiful red and green tints colour them at intervals; that waves of light undulate over them; that currents of light succeed each other; and, in fine, that the vast firmament presents one immense and magnificent dome of light, reposing on the snow-covered base supplied by the ground—which itself serves as a dazzling frame for a sea, calm and black as a pitchy lake—and some idea, though an imperfect one, may be obtained of the splendid spectacle which presents itself to him who witnesses the aurora from the Bay of Alten.

The corona, when it is formed, only lasts for some minutes: it sometimes forms suddenly, without any previous bow. There are rarely more than two on the same night; and many of the auroras are attended with no crown at all.

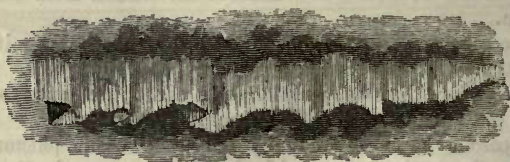
The corona becomes gradually faint, the whole phenomenon being to the south of the zenith, forming bows gradually paler, and generally disappearing before they reach the southern horizon. All this most commonly takes place in the first half of the night, after which the aurora appears to have lost its intensity: the pencils of rays, the bands, and the fragments of bows appear and disappear at intervals; then the rays become more and more diffused, and ultimately merge into the vague and feeble light which is spread over the heavens, grouped like little clouds, and designated by the name of *auroral plates* (*plaques aurorales*). Their milky light frequently undergoes striking changes in its brightness, like motions of dilatation and contraction, which are

propagated reciprocally between the centre and the circumference, like those which are observed in marine animals called Medusæ. The phenomena become gradually more faint, and generally disappear altogether on the appearance of twilight. Sometimes, however, the aurora continues after the commencement of daybreak, when the light is so strong that a printed book may be read. It then disappears, sometimes suddenly; but it often happens that, as the daylight augments, the aurora becomes gradually vague and undefined, takes a whitish colour, and is ultimately so mingled with the cirrho-stratus clouds, that it is impossible to distinguish it from them.

Some of the appearances here described are represented in figs. 4, 5, 6, 7, copied from the memoir of M. Lottin.

Fig. 6.

Fig. 7.



The height of the auroras has not certainly been ascertained; but as they are atmospheric phenomena, and scarcely above the region of the clouds, and as they certainly partake of the diurnal motion of the earth, it does not seem probable that their elevation in any case can exceed a few miles.

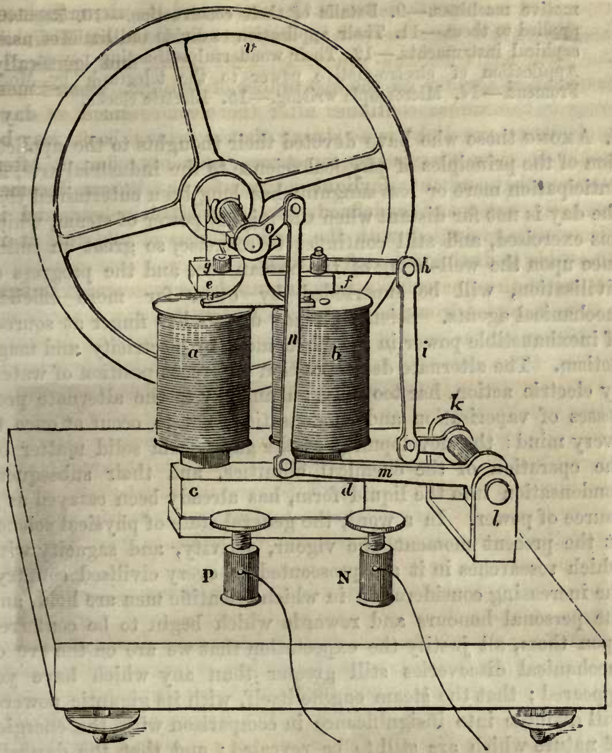


Fig. 2.

ELECTRO-MOTIVE POWER.

CHAPTER I.

1. Prospects of improvement in motive power by the application of electricity.—2. Example of its practical application in the workshop of Mons. Froment, mathematical instrument maker in Paris.—3. Mention of it in Catalogue of the Great Exhibition in Hyde Park.—4. Property of electro-magnets.—5. Alternate transmission and suspension of the current.—6. How this produces a moving power.—7. Voltaic piles used by Mons. Froment.—8. Forms of his electro-

motive machines.—9. Details of their construction.—10. Regulator applied to them.—11. Their application to divide the limbs of philosophical instruments.—12. Their wonderful self-acting power.—13. Application of electro-motive power to the telegraph by Mons. Froment.—14. Microscopic writing.—15. Electric clocks.

1. AMONG those who have devoted their thoughts to the application of the principles of physical science to the industrial arts, an anticipation more or less sanguine has long been entertained that the day is not far distant when the mighty power of steam, which has exercised, and still continues to exercise, so great an influence upon the well-being of the human race and the progress of civilisation, will be superseded by other far more efficient mechanical agents. Science already directs her finger at sources of inexhaustible power in the phenomena of electricity and magnetism. The alternate decomposition and recomposition of water, by electric action, has too close an analogy to the alternate processes of vaporisation and condensation, not to occur at once to every mind: the development of the gases from solid matter by the operation of the chemical affinities, and their subsequent condensation into the liquid form, has already been essayed as a source of power. In a word, the general state of physical science at the present moment, the vigour, activity, and sagacity with which researches in it are prosecuted in every civilised country, the increasing consideration in which scientific men are held, and the personal honours and rewards which begin to be conferred upon them, all justify the expectation that we are on the eve of mechanical discoveries still greater than any which have yet appeared; that the steam engine itself, with its gigantic powers, will dwindle into insignificance in comparison with the energies of nature which are still to be revealed; and that the day will come when that machine, which is now extending the blessings of civilisation to the most remote skirts of the globe, will cease to have existence except in the page of history.

2. It is not, however, generally known, that there exists in Paris an establishment for the fabrication of philosophical instruments, or rather of that class of those instruments which in that country are distinguished as instruments of precision, in which electro-magnetism is and has been for several years back applied with complete success, as a moving power on a considerable scale.

3. In the Crystal Palace in Hyde Park, a small modest-looking stall furnished with theodolites and some models of electro-magnetic apparatus might have been seen, bearing the inscription of Gustave Froment; and in the Great Illustrated and commentated Catalogue there appeared the three following lines:—

"GUSTAVE FROMENT—5 *rue Ménilmontant, Paris.*

"Scientific Instruments. Theodolite; and various models of electro-motive power."

Assuredly brevity could no further go. Never was presented a more conspicuous example of modest reserve on the part of artistic genius the most exalted. No effort seems to have been thought of by the exhibitor, even to call the attention of the commentators of the catalogue, to the claims of these productions of the highest scientific art; for, while comment and panegyric have been liberally, not to say profusely, accorded to exhibitors, who, whatever may have been their merits, presented claims immeasurably below him whose illustrious labours we are about to notice, not a single word of comment drew the attention of the general public to objects, the fabrication of which would have presented the highest attractions, even to the most idle and incurious of the loungers of the Crystal Palace.

Happily for the cause of science and art, and for that of justice, the same neglect did not prevail among the eminent persons to whom the distribution of honours was entrusted. They discerned and appreciated the titles of M. Froment, and most justly accorded him, by an unanimous vote, a council medal. The authorities of his own country added to this the decoration of the Legion of Honour.

If M. Froment were as ambitious of personal *éclat* as of the attainment of perfection in his workmanship, he would have transported to the Crystal Palace a part of the beautiful machinery of his Parisian workshop, and would have exhibited, not his theodolite alone, but the process of its fabrication. Had he done this (and he might have accomplished it without difficulty), his station in the Great Exhibition as an object of attraction would have rivalled even the Koh-i-noor.

The inventions and improvements of M. Froment, in the construction of instruments of precision, and of scientific apparatus generally, can nowhere be so advantageously seen and appreciated as in his own workshop in Paris. There may be seen not only the finished instruments and machines, but their practical application *in the construction of each other!* There may be seen electro-magnetism applied on a large scale, as a permanent and regular moving power, in the fabrication of mathematical and optical instruments.

The electro-motive machines of M. Froment, which are very various in form, magnitude, and power, derive, nevertheless, their motive force from one common principle, which is the same that has been applied in certain forms of electro-magnetic telegraph.

4. The property of the electro-magnet has been already so fully

explained in our Tract upon the "Electric Telegraph," page 196, that it will be sufficient briefly to recapitulate the general physical principles from which this property arises.

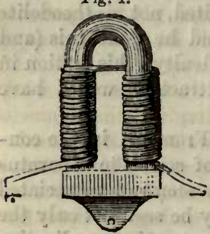
If a voltaic current be conducted spirally round a rod of soft iron, the iron will become magnetic, and will continue magnetic so long as the current passes round it. Its acquisition of the magnetic virtue is simultaneous with the transmission of the current. It is not gradual but instantaneous. The very instant the current is transmitted, the magnetic virtue is imparted to the iron, and does not afterwards increase in intensity.

The loss of the magnetic virtue, upon the suspension of the current, is equally instantaneous and complete. The very instant the current is discontinued, the iron ceases to be magnetic.

The subtlety of the electric fluid, and the celerity of its propagation, are such that it is capable of being transmitted and suspended instantaneously, and, however short the interval may be between the instants of its transmission and suspension, it will, during that interval nevertheless, impart to the iron the magnetic property. So true is this, that it is practically found that the current may be alternately transmitted and suspended hundreds or even thousands of time in a single second, and in these short intervals the iron will alternately acquire and lose the magnetic virtue.

The manner in which the voltaic current is transmitted spirally round the iron bar is as follows:—The wire upon which the current is transmitted is wrapped with silk or cotton thread, which being a non-conductor of electricity, will prevent the lateral escape of the fluid, which will therefore pass along the wire within the coating of thread as water or air would pass along a tube. The wire thus covered is coiled spirally round the bar of soft iron, which may or may not be bent into the horse-shoe form, as shown in fig. 1. One end of the wire being put in connection with the positive, and the other with the negative pole of the voltaic battery; the current will be transmitted upon it, and will be prevented from passing from one coil of the wire to the contiguous one, by the interposition of the silk or cotton thread. So long as the current is thus continued, the iron, whatever be its form, will be magnetic, one end having the properties of the north and the other of the south magnetic pole.

Fig. 1.



5. By an expedient to which an infinite variety of forms may be given, the current can be alternately transmitted and suspended

with any desired degree of rapidity; and, by varying the power of the battery, the number of coils of the spiral wire, and the magnitude of the iron bar, a magnetic force of any desired intensity can be produced.

A piece of iron, called an armature, is presented to one or both of the poles of the magnet towards which it is attracted, while the current is transmitted with a force proportionate to the intensity of the magnetism; and when the current is suspended, the armature either falls from the magnet by its own weight, or is withdrawn from it by the action of a spring, or other mechanical expedient, provided for the purpose.

The armature may be placed between two magnets, which are alternately acted upon by the electric current, which is transmitted round each in the intervals of its suspension round the other. The armature will then be moved alternately to and fro between the two magnets.

6. In this manner, by alternately suspending and transmitting the current on the wire which is coiled round the electro-magnet, the magnet and its armature receive an alternate motion to and from each other, similar to that of the piston of a steam-engine, or the foot of a person who works the treddle of a lathe. This alternate motion is made to produce one of continued rotation by the same mechanical expedients as are used in the application of any other moving power.

The force with which the electro-magnet and its armature attract each other, determines the power of the electro-motive machine, just as the pressure of steam on the piston determines the power of a steam-engine. This force depends on the nature and magnitude of the galvanic pile which is employed.

7. The pile used by M. Froment for the lighter sort of work, such as that of driving his engines for dividing the limbs of astronomical and surveying instruments, and microscopic scales, is that of Daniel, consisting of about twenty-four pairs. Simple arrangements are made by means of commutators, reometers, and reotropes, for modifying the current indefinitely in quantity, intensity, and direction. By merely turning an index or lever in one direction or another, any desired number of pairs may be brought into operation, so that a battery of greater or less intensity may be instantly made to act, subject to the major limit of the number of pairs provided. By another adjustment, the copper elements of two or more pairs, and at the same time their zinc elements, may be thrown into connection, and thus the whole pile, or any portion of it, may be made to act as a single pair, of enlarged surface. By another adjustment, the direction of the current can be reversed at pleasure. Other adjustments, equally

simple and effective, are provided, by which the current can be turned on any particular machine, or directed into any room in which it may be required.

The pile used for heavier work, is a modification of Bunsen's charcoal battery, in which dilute sulphuric acid is used in the porous porcelain cell containing the charcoal, as well as in the cell containing the zinc. By this expedient the noxious fumes of the nitric acid are removed, and although the strength of the battery is diminished, sufficient power remains for the purposes to which it is applied.

8. The forms of electro-motive machines constructed by M. Froment are very various. In some the magnet is fixed, and the armature moveable ; in some both are moveable.

In some there is a single magnet and a single armature. The power is in this case intermittent, like that of a single-acting steam-engine, or that of the foot in working the treddle of a lathe, and the continuance of the action is maintained in the same manner by the inertia of a fly-wheel.

In other cases two electro-magnets and two armatures are combined, and the current is so regulated, that it is established on each during the intervals of its suspension on the other. This machine is analogous in its operation to the double-acting steam-engine, the operation of the power being continuous. The force of these machines may be augmented indefinitely, by combining the action of two or more pairs of magnets.

Another variety of the application of this moving principle, presents an analogy to the rotatory steam-engine. Electro-magnets are fixed at equal distances round a wheel, to the circumference of which the armatures are attached at corresponding intervals. In this case the intervals of action and intermission of the currents are so regulated, that the magnets attract the armatures obliquely as the latter approach them, the current, and consequently the attraction, being suspended the moment contact takes place. The effect of this is, that all the magnets exercise forces which tend to turn the wheel on which the armatures are fixed constantly in the same direction, and the force with which it is turned is equal to the sum of the forces of all the electro-magnets which act simultaneously.

This rotatory electro-motive machine is infinitely varied, not only in its magnitude and proportions, but in its form. Thus in some the axle is horizontal, and the wheel revolves in a vertical plane ; in others the axle is vertical, and the wheel revolves in a horizontal plane. In some the electro-magnets are fixed, and the armatures moveable with the wheel ; in others both are moveable. In some the axle of the wheel which carries the armatures is itself

moveable, being fixed upon a crank or eccentric. In this case the wheel revolves within another, whose diameter exceeds its own by twice the length of the crank, and within this circle it has an hypocycloidal motion.

Each of these varieties of the application of this power, as yet novel in the practical operations of the engineer and manufacturer, possesses peculiar advantages or convenience, which render it more eligible for special purposes.

9. *Electro-motive machines.*—To render this general description of M. Froment's electro-motive machines more clearly understood, we shall add a detailed explanation of two of the most efficient and useful of them.

In the machine represented in fig. 2, *a* and *b* are the two legs of the electro-magnet; *c d* is the transverse piece uniting them, which replaces the bend of the horse-shoe; *e f* is the armature confined by two pins on the summit of the leg *a* (which prevent any lateral deviation), the end *f* being jointed to the lever *g h*, which is connected with a short arm projecting from an axis *k* by the rod *i*. When the current passes round the electro-magnet, the lever *f* is drawn down by the attraction of the leg *b*, and draws with it the lever *g h*, by which *i* and the short lever projecting from the axis *k* are also driven down. Attached to the same axis *k* is a longer arm *m*, which acts by a connecting rod *n* upon a crank *o* and a fly-wheel *v*. When the machine is in motion, the lever *g h* and the armature *f* attached to it recover their position by the momentum of the fly-wheel, after having been attracted downwards. When the current is again established, the armature *f* and the lever *g h* are again attracted downwards, and the same effects ensue. Thus, during each half-revolution of the crank *o*, it is driven by the force of the electro-magnet acting on *f*, and during the other half-revolution it is carried round by the momentum of the fly-wheel. The current is suspended at the moment the crank *o* arrives at the lowest point of its play, and is re-established when it returns to the highest point. The crank is therefore impelled by the force of the magnet in the descending half of its revolution, and by the momentum of the fly-wheel in the ascending half.

Fig. 3.

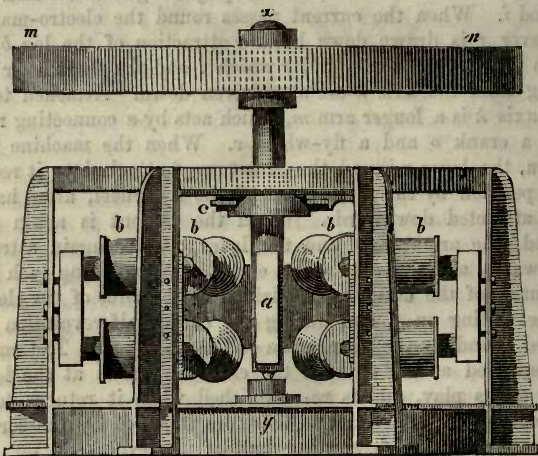
The contrivance called a *distributor*, by which the current is alternately established and suspended at the proper moments, is represented in fig. 3, where *y* represents the transverse section of the axis of the fly-wheel; *r*, a spring which is kept in constant contact with it; *x*, an eccentric fixed on the same axis *y*, and revolving with it and *r′* another spring similar to *r*,

which is acted upon by the eccentric, and is thus allowed to press against the axis y during half the revolution, and removed from contact with it during the other half-revolution. When the spring r' presses on the axis y the current is established; and when it is removed from it the current is suspended.

It is evident that the action of this machine upon the lever attached to the axis k is exactly similar to that of the foot on the treddle of a lathe or a spinning-wheel; and as in these cases, the impelling force being intermittent, the action is unequal, the velocity being greater during the descending motion of the crank o than during its ascending motion. Although the inertia of the fly-wheel diminishes this inequality by absorbing a part of the moving power in the descending motion, and restoring it to the crank in the ascending motion, it cannot altogether efface it.

Another electro-motive machine of M. Froment is represented in elevation in fig. 4, and in plan in fig. 5. This machine has the

Fig. 4.

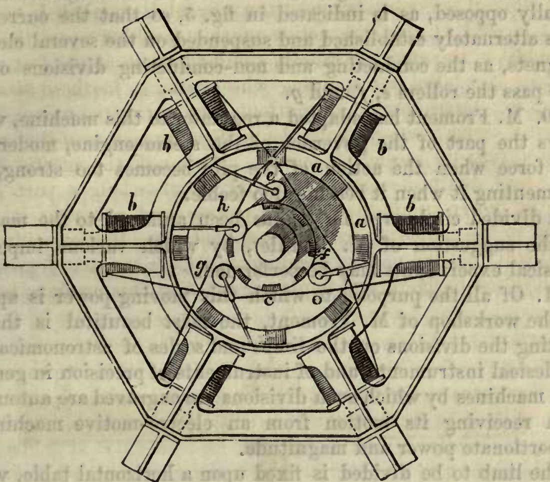


advantage of producing a perfectly regular motion of rotation, which it retains for several hours without sensible change.

A drum, which revolves on a vertical axis x y, carries on its circumference eight bars of soft iron a placed at equal distances asunder. These bars are attracted laterally, and always in the same direction, by the intermitting action of six electro-magnets b, mounted in a strong hexagonal frame of cast-iron, within which the drum revolves. The intervals of action and suspension

of the current upon these magnets are so regulated that it is established upon each of them at the moment one of the bars of

Fig. 5.



soft iron *a* is approaching it, and it is suspended at the moment the bar begins to depart from it. Thus the attraction accelerates the motion of the drum upon the approach of the piece *a* towards the magnet *b*, and ceases to act when the piece *a* arrives in front of *b*. The action of each of the six impelling forces upon each of the eight bars of soft iron attached to the drum is thus intermitting. During each revolution of the drum, each of the eight bars *a* receives six impulses, and therefore the drum itself receives forty-eight impulses. If we suppose the drum to make one revolution in four seconds, it will therefore receive a succession of impulses at intervals of the twelfth part of a second, which is practically equivalent to a continuous force.

The intervals of intermission of the current are regulated by a simple and ingenious apparatus. A metallic disc *c* is fixed upon the axis of rotation. Its surface consists of sixteen equal divisions, the alternate divisions being coated with non-conducting matter. A metallic roller *h*, which carries the current, presses constantly on the surface of this disc, to which it imparts the current. Three other metallic rollers *e*, *f*, *g* press against the edge of the disc, and, as the disc revolves, come alternately into contact with the conducting and non-conducting divisions of it. When they touch

the conducting divisions, the current is transmitted; when they touch the non-conducting divisions, the current is interrupted.

Each of these three rollers *e*, *f*, *g* is connected by a conducting wire with the conducting wires of two electro-magnets diametrically opposed, as is indicated in fig. 5, so that the current is thus alternately established and suspended on the several electro-magnets, as the conducting and non-conducting divisions of the disc pass the rollers *e*, *f*, and *g*.

10. M. Froment has adapted a regulator to this machine, which plays the part of the governor of the steam-engine, moderating the force when the action of the pile becomes too strong, and augmenting it when it becomes too feeble.

A divided circle *m n*, fig. 4, has been annexed to the machine at the suggestion of M. Pouillet, by which various important physical experiments may be performed.

11. Of all the purposes to which this moving power is applied in the workshop of M. Froment, the most beautiful is that of making the divisions on the limbs and scales of astronomical and geodesical instruments, and of instruments of precision in general. The machines by which such divisions are engraved are automatic, each receiving its motion from an electro-motive machine of proportionate power and magnitude.

The limb to be divided is fixed upon a horizontal table, which receives a slow and intermitting progressive motion from a fine screw. This screw itself is urged at intervals by a ratchet-wheel. The catch or click by which this ratchet-wheel is driven, can be so adjusted as to take one, two, or several teeth at each stroke, and therefore to move the table carrying the limb through a greater or less space, according to the magnitude of the divisions to be engraved upon the scale. Over the limb to be engraved is placed the point or edge by which the incision is produced, which is either hardened steel or diamond. During the progressive motion of the table carrying the limb, this cutter is elevated, so as not to touch it. In the intervals during which the motion of the table is suspended, the cutter descends upon the limb, and, being pressed upon it with sufficient force, is drawn upon it in a direction at right angles to the motion of the table, thus engraving upon it the line which marks the division. Thus the motions of the limb and the cutter are alternate, each being in action while the other is at rest. The cutter is fixed upon an arbor which derives its motion from the same crank which works the ratchet, but its connection is arranged so as to give them the alternate action just mentioned.

By an arrangement provided in this arbor, a more extended motion is imparted to the cutter at every tenth stroke of the

ratchet, the effect of which is, that every tenth division made upon the limb by the cutter is distinguished by a longer line than the intermediate divisions.

In some cases both the motions above described are imparted to the cutter, the limb upon which the divisions are engraved being kept at rest. The cutter is, in that case, alternately impressed with two motions, one which transfers it from division to division while it is raised from the limb, and the other in a direction at right angles to this, while it is pressed upon the limb, and makes the incision which marks the division.

These dividing instruments vary in form and magnitude according to the purposes to which they are applied.

Those which are used for engraving the divisions on the circular limbs of theodolites and other instruments of the larger class, consist of a circular metallic table of solid construction and suitable magnitude, to which a motion round its centre in its own plane is imparted by means of a finely-constructed worm, which works in teeth formed on the edge of the circular table itself. Means are provided by which the circular limb to be divided can be fixed upon this table, so as to be exactly concentric with it, and to be moved with it. The cutter is fixed so as to slide upon a rod which is extended over this table and parallel to it. The cutter can, by this arrangement, be adjusted at any required distance from the centre of the table, so as to correspond to a circular limb of any magnitude not exceeding that of the table.

In the process of engraving the divisions, the worm and the cutter are moved alternately by self-acting mechanism, deriving its motion from the electro-motive machine by which all the apparatus of the workshop is driven. The worm is so adjusted, that by each action on the table, the limb to be engraved is moved under the cutter (which is then elevated so as not to act upon it), through a space equal to the interval between the divisions. The worm then stops, and the limb being at rest, the cutter descends upon it, and is drawn through a space equal to the length of the line to be engraved, and the division is accordingly marked upon the limb. The cutter is then again elevated, and the limb again moved under it by the worm, and so on.

In this case the divisions which mark degrees are distinguished from the intermediate minutes by larger lines, mechanical arrangements being provided in the wheelwork by which the motion of the cutter is thus affected.

12. All these machines are self-acting. The limb or scale to be divided being once placed on the table of the dividing engine, no further interference of the human hand is needed. The machine of itself begins its work at an appointed hour, minute, and

second, and when the last division of the scale has been engraved, it not only suspends its own action, but stops that of the electro-magnetic machine by which it is impelled. These automatic arrangements must not be regarded as mere mechanical superfluities, upon which the boundless fertility of invention which characterises the genius of M. Froment has been lavished; they are of great practical value and importance. It happens, for example, that in these delicate operations, the tremor of the ground on which the workshop stands, produced by the movement of vehicles of transport in the adjoining streets, affects in a sensible degree the motion of the cutting point. It is therefore always preferable to execute the most delicate work in the dead of the night. Now, by the automatic contrivances above mentioned, this can be accomplished without imposing on the superintendent the necessity of watching. A clock, provided with an apparatus similar in principle to a common alarum, is put in mechanical connection with the dividing machine, and is set so as to start the machine at any desired hour. This being done, and the limb to be divided being fixed upon the table under the cutter, the apparatus may be left to itself; the superintendent may retire to rest, and at the hour of the night which has been selected, the electro-motive machine will be started by the clock, and the dividing engine will commence, continue, and complete its work with the most admirable certainty and precision, and, when completed, the electro-motive machine will be stopped, and all reduced to rest.

The magnitude of the dividing engine for microscopic scales, is about 8 inches long by 6 inches wide, and 4 inches high. The magnitude of the electro-motive engine necessary to drive it, is not more than 4 inches square in its base, and 3 inches high.

It is scarcely necessary to observe, that the more minute class of these scales can only be seen by the aid of a microscope of high magnifying power. This will be easily understood when it is considered that, in a space measuring a tenth of an inch in length, there are in the more minute scales, 2500 divisions. Such is, nevertheless, the precision of the execution, that when looked at with a sufficiently high magnifying power, the lines exhibit the most perfect evenness and regularity.

13. Among the inventions of M. Froment, which may be also seen in operation in his establishment, are two electric telegraphs, one of which transmits its messages by enabling an operator at one station to direct an index, which moves upon a dial-plate, to any desired letter of the alphabet, those letters being engraved around the dial like the hour-mark upon a clock or watch. The

transmitting agent has before him a row of keys, like those of a piano-forte (fig. 6), upon which the letters of the alphabet are

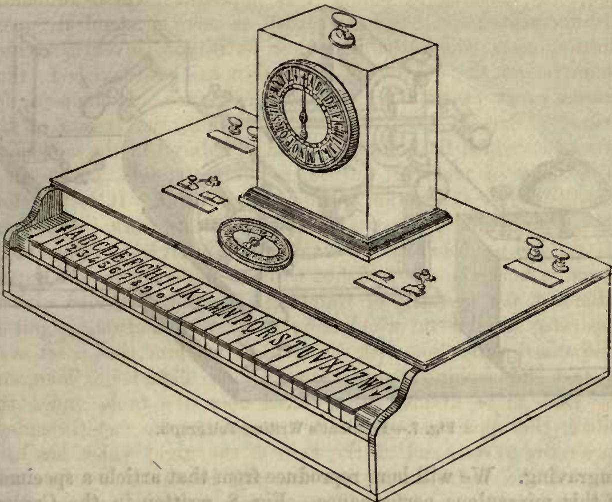


Fig. 6.—Froment's Alphabetical Telegraph.

engraved. When he presses down the key upon which any letter is inscribed, the index of the dial at the distant station with which he is in communication turns, and stops when it points at the same letter. In this way, by indicating the successive letters of the words composing the message, the despatch is transmitted.

The mechanism by which this is accomplished, is fully described in our Tract on the "Electric Telegraph," par. 205.

Another form of electric telegraph (fig. 7), which writes the message it transmits, may also be seen in operation in M. Froment's workshop.

The message is transmitted in this instrument by pressing down a key successively by the finger, the key being held down a longer or shorter time, in the same manner as a pianist would play notes of greater or less length. Varying marks of corresponding lengths are made upon paper by a pencil at the distant station, the paper being moved under the pencil by suitable mechanism. For a description of this telegraph see also our Tract on the "Electric Telegraph," par. 207.

14. Another of the results of the mechanical ingenuity of this artist, which may be seen at his workshop, which if not the most useful is assuredly the most astonishing, and to many the most

incomprehensible, is his microscopic writing, which has been already noticed in our Tract on Microscopic Drawing and

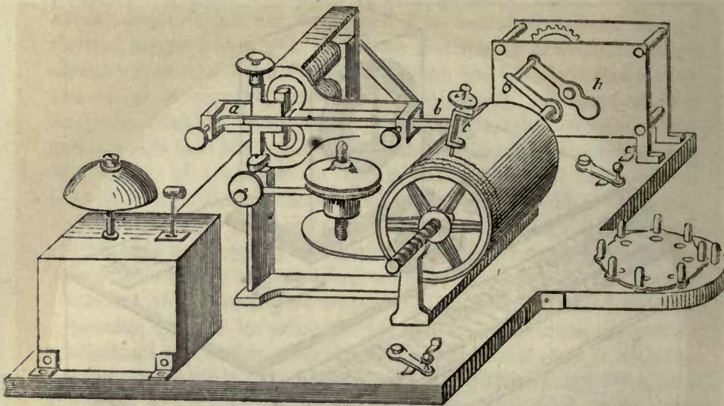


Fig. 7.—Froment's Writing Telegraph.

Engraving. We will here reproduce from that article a specimen of this miraculous performance. Fig. 8, written in the Crystal Palace, in 1851, within a circular space, having the diameter of the 30th of an inch.

The details of the method by which this microscopic writing is executed have not yet been made public, but we believe the inventor is preparing a memoir on the subject, to be presented to the Academy of Sciences.

15. This brief notice of the application of electro-motive power must not be concluded without mentioning its remarkable application to chronometers, examples of which may be seen in many parts of this country, one of which is presented daily and nightly in the Strand, near the Electric Telegraph Office.

The general principle of this beautiful application of physical science to the economy of life is easily explained.

The hand of a clock or watch moves not uniformly, but by a succession of starts, as may be plainly seen in the case of a seconds' hand of a watch or clock. The same intermitting motion affects the minute and hour hands, but their movement from second to second is so minute that it is imperceptible to the eye.

Now, from what has been already explained, it will be evident that a similar intermitting motion can be imparted to the contact piece of an electro-magnet by the alternate transmission and suspension of the current. If, therefore, by any means the electric

current can be transmitted and suspended alternately with chronometric regularity, so that, for example, the interval of its

Fig. 8.—Appearance as seen in the field of the Microscope, the outer circle being only 1-30th of an inch in diameter.

transmission and suspension shall be exactly one second of time, then the motion to and fro of the contact piece will also be performed with the same chronometric regularity, in intervals of one second. It is evident, therefore, that if such a contact piece, so moving, be put in connection with a properly constructed frame of wheel-work, it may be used to impart motion to the hands of a timepiece.

It appears also that the same regularly intermitting current may be transmitted to any number of timepieces, at any distance whatever from each other, by means of conducting wires similar to those of the electric telegraph; and since the length of such intermediate wires does not affect their power of transmission, it

follows that the same current can simultaneously impart a perfectly regular chronometric motion, to all the clocks dispersed over a large country.

It remains only to show how the regularity of the intermission of the current can be obtained. This is accomplished by the obvious expedient of putting the commutator, by the motion of which the current is alternately transmitted and interrupted, in connection with a well-regulated chronometer, the pendulum of which shall, in that case, itself alternately transmit and suspend the current.

Among the numerous applications of electric power to be seen in the workshops of M. Froment, are a series of electric clocks constructed nearly upon the principle above described. The motion of each clock is in this case maintained by a small weight, which is alternately raised and lowered upon an appendage of the pendulum by means of an iron counterweight, which is itself alternately raised and disengaged by an electro-magnet, each time that the appendage, by its contact with the weight, opens and closes the voltaic circuit, or, what is the same, transmits and suspends the current.

The motion of the clock is maintained by a constant weight, without friction and without the application of oil, with great regularity, while the electric current, which is transmitted through it in the intervals of each oscillation, transmits to a distance the chronological indications upon a series of dials, the hands of which are moved by a mechanism, analogous to that which moves the index of an electric telegraph of the kind used on the continental railways.

LONDON, *April*, 1856.

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